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Effect of road noise on certain aspects of driver's performance.

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EFFECT OF ROAD NOISE

ON

CERTAIN ASPECTS OF DRIVER'S PERFORMANCE

A THESIS

Presented in Partial Fulfilment of the

Requirements for the Degree of

Master of Applied Science

at the

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by

ROBERT LUIZ

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May, 1973.

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ABSTRACT

The effect of road noise on performance time in a simulated driving task has been studied. A simulator, which comprises of the front half of a car enclosed in a wooden frame and a road movie projected from the rear on a screen which is placed in front of the driver was used. The simulated driving task was performed by 22 subjects at three different road speeds, i.e. 30, 40, and 50 miles per hour and under three different road noise levels, i.e. 80, 90, 100 dB. Experimental results indicate that noise does affect the performance time. Subject's age and driving experience were not found to be significant variables in the study.

TO MY MOTHER

ACKNOWLEDGEMENTS

The author takes this opportunity to express his appreciation to Dr. A. Raouf for his guidance, encouragements and inspiration in completing this thesis.

The author also extends his appreciation to all committee members, especially Prof. N. G. Eley for his guidance, suggestions and wholehearted participation in the experiment.

Sincere thanks to Mr. L. Cory of Electronics Research Shop and Mr. O. Brudy of Mechanical Research Shop for allowing me to use their facilities in order to build the essential components for the Simulator.

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Gratitude is also due the subjects for their patient participation in conducting the experiment.

Finally, the author wishes to express his greatfulness to his wife, for her financial and moral supports which made this work possible.

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CHAPTER ONE

INTRODUCTION

Researchers interested in studying human performance in man machine systems agree that environmental factors such as temperature, noise and vibrations are factors influencing human performance. A Vehicular Transport System (VTS) which is comprised of the driver, the vehicle, surrounding traffic, and environment, is a special kind of man-machine system (43). In this system the driver's behaviour encompasses sensory and perceptual processes, decision making and psychomotor skills. Although, the number of drivers killed while performing in VTS (56,000 annually in the U.S. alone) is considerably higher than industrial workers killed while performing industrial tasks, one does not find many documented studies pertaining to the effects of environment on driver behaviour

In North America the automobile manufacturers are not only trying to minimize the after effects of accidents by providing seat belts, shoulder harness, padded dash boards, collapsable steering columns, energy absorbing bumpers, and air bags, but are also making the automobile very comfortable. Number of cars equipped with air conditioners is increasing every year. Air conditioners not only provide a controlled temperature inside the automobile, but also cut down "road and wind noises" considerably.

The effect of road noise on driver behaviour has not been sufficiently investigated. Consequently present study in which subjects performed a simulated driving task under various noise levels and road speeds was undertaken. The three noise levels selected for this study are similar to the noise levels usually experienced in day to day city driving. Three speed levels allowed for city driving were selected for this study.

Using a total of 22 subjects a randomized complete factorial experiment was performed on the simulator designed and built by the University of Windsor.

The subjects selected for this study were holders of the Ontario Drivers Licence. Data pertaining to their driving experience in terms of miles and years were obtained. Tests were performed to determine the coefficients of correlation between the performance times and the number of years of experience and approximate total milage driven.

CHAPTER TWO

Literature Survey

For many years scientists and engineers concerned with the design and operation of man-machine systems have been continuously working to improve safety, controls and comfort of the automobile. An automobile is an excellent example of a man-machine system, with which most people come into contact one time or another. Therefore, mechanical as well as electrical designs in an automobile should be combatable to the psychological and physiological characteristics of a driver. Learner (36) and Forbes (24) directed their research work mainly towards establishing some criterion where by the efficiency of the individual driver or steering system can be measured and compared with each other. Laur, Suhr, and Allgair (35) suggest that better drivers turn the steering wheel less, use less gasoline, work the accelerator less, and are less severe on brakes than the poor drivers. Literature suggest no absolute method to define driving performance, rather it depends on experimental conditions imposed restrictions, masked and unmasked parameters and many other related factors.

Factors such as reaction time, fatigue, glare, temperature, alcohol, tracking behaviour, vibration and noise, have been the subjects for researchers during the last few decades. Darret, Kobayashi, and Fox, (3), conducted feasibility studies of a driver reactions to sudden pedestrian emergencies. Johansson and Rumar (33) tested 321 drivers for their brake reaction times and found that every driver, male or female, has longer reaction time when signals occurred randomly. Further investigation by Davies and Watts reveals that:

(1) Foot movement time for females is 25% slower than males when both gas pedal and brake pedal are kept at the same level.

(2) Foot movement time are the same for both male and female when the brake pedal was 6 inches higher than the gas pedal.

It is often assumed that simple reaction time and accidents are closely related. However, little is known to support this argument, mainly because of the difficulty to create or simulate genuine accidents in the laboratory. Albert Burg (14) compared the driving and accidents records of 769 drivers and summarized that milage, sex and age are factors influencing driving records.

Driving is usually a challenging experience. However, under normal conditions the driver can produce good or poor performances since he is subjected to information feedback from road signs and is exposed to environmental conditions. When the drivers begin to tire he looses much of his attention to feedback. As a result he cannot track the vehicle as well as when he is alert. Even though most people will be highly motivated to do their best when being tested, researchers agree that driver fatigue will have effect on steering wheel reversals, speed change rates, and average speed of the vehicle. As drivers become fatigued he will accept wider tolerances for both vehicle tracking and speed control. As a result the driver tends to take more risks when fatigued. Platt (48) attempted to measure fatigue of drivers over long driving intervals having steering wheel reversals as a measurement of driving performance and found, in general, more skilled drivers produced lower steering wheel reversals. He catagorizes fatigue as:

(1) Subjective fatigue defined as the feeling of being tired.

(2) Physiological fatigue as determined by bodily change.

(3) Objective fatigue when performance of a task shows a progressive deterioration.

Temperature has been found to cause deterioration in a wide range of tasks including vigilance, and tracking. Pepler (45) concluded that tracking performance deteriorate as temperature increases. Lamburn suggests that the most comfortable driving is when the temperature inside the car is kept at 75°F.

Vibration in an automobile is considered to include the oscillatory motion of the vehicle travelling over bumpy roads. Excessive vibrations have been found harmful to both human beings and animals. Alcohol, carbon monoxide, tobacco smoke, drugs, produce poor attention, slower and less dependable response, less self control and deterioration in reaction time.

One of the factors which has not been explored sufficiently is the effect of noise on driver performance. It has been shown that assembly line workers made more mistakes under high intensity noise (34). Experiments shows that high intensity high frequency noise has more adverse effect on performance than a low frequency high intensity noise. In the presence of noise the subject may loose task information because he is responding directly or indirectly to noise. Noise has generally been studied as a distracting stimulus and has been found to impair performance in psychometeric tasks. Both Morgan (42) and Ford demonstrated that removal of noise has the same kind of decremental effect as the introduction of the same noise. Broadbent (11) found that high frequency noise gave more errors in performance and response time was slower at lower frequency. Sanders (52) noted that noise affects work - it affects increasingly irregularity of response time rather than a general decrease in number of responses. Broadbent (38) showed that noise does produce a deliterious effect on performance task that are unpredictable with respect to time of occurance. However, Watkins (57) found that the detection performance was substantially better when noise was presented during the observation intervals than when it was continuously present. Brown (12), on the other hand, noted a beneficial effect of a group of subjects who drove through heavy and light traffic while listening to a recorded program of music.

Thus literature does not indicate the effect of noise on the performance of a driver. Thus a study on this topic was considered desirable. The task was to select a proper parameter that represents the performance of a driver and a meaningful measuring method to record the quantitative results.

2.1 PERFORMANCE TIME

There has been considerable work done on response time and a brief survey of which is given below.

One of the interesting aspects of the stimulus - Response mechanism is that there is a definite time interval between the time when the stimulus is applied and the response it produces. This time interval, widly known as the Response Time, is neither the same for the same individual under different conditions nor the same for different individuals under the same conditions. It may be concluded that the Response Time is an index of an individual's independent characteristic, a parameter by which an individual's physiological and psychological characteristic may be measured.

A knowledge of Response Time leads us to a better understanding of the nature of the psychic activities and their relationships to the physiology of the individual driver. Studies on Response Times have been extremely helpful in judging the qualifications necessary for efficient drivers, pilots and others who must react quickly to stimulus. The natural dependency of response time on an individual's characteristics and its tendency to change as the conditions change prompted many scientists to explore further in this field. The general tendencies of Response Time, as postulated by Siwek, (44), are:—

(1) That it varies from one individual to another.

(2) That it is longer in childhood and in old age than in maturity.

(3) That fatigue lengthen it and practice shortens it.

One of the first studies on Response Time was that Obersteiner (44) studied Response Times of subjects who were sleepy, fatigued, suffering from a head ache and found that these conditions all lengthened Response Time as compared with the Response Times of the same subjects when they were normal. Crude technique and the conclusions drawn on insufficient number of cases made these results of little or no value.

Draxin's (18A) experimental findings are interpreted as evidence in favour of the view that response time reflects the subjects state of readiness for the stimulus. Botwinic and Brinley, (9), Jointley, and Hershenson, (30), independently showed that response time was longer with visual stimulus than with auditory stimulus. Robinson (50) found that response time decreased with increased luminance or area under equal energy conditions and is independent of duration.

It has been shown that response time is shorter when the ready signal is applied before the stimulus than an uncertain, random signal. Berch (2), found that response time showed a slowness when uncertainty of stimulus is introduced and this slowness was reduced or eliminated by introducing a ready signal. Also, Bernstein, Shurman and Forester, (7), concluded that changes in stimulus uncertainty produced linear changes in response time.

Literature has provided sufficient proof that response time varies with experimental set ups, conditions and methods of experiments. Experiments such as measuring response time for:

(a) Light added to light.

(b) Light added to noise.

(c) Noise added to light.

(d) Clicks added to noise.

(e) Tone added to noise.

(f) Tones added to tones.

All provide varying values of response time. Actual procedure of these experiments, one way or the other involved in pressing a telegraph or pushing or pulling levers or verbal responses of "yes" or "no".

These and many other factors strongly suggests a need to measure the variation of response time related to automobile driving. A number of feasibility studies conducted on driver response times and various methods of measurements are worth mentioning at this point. Typical tracking tasks involve control of a single variable and the measurement is time averaged. Crossman (17), using a laboratory simulator, showed that on a straight road the lateral position error showed a marked periodicity of 0.2Hz. McLaren and Hoffman (39), writes "In a simple steering task drivers make most of their control movements within the two frequency bands of 0.1 to .3H_z and .35 to .6H_z". Michaels and Cozan, (41), found when an object is placed near the path of a driver, a lateral movement away from the object occurs. Another element in the real world driving task is the anticipatory information that is perceived by the driver at some point down the road stored until needed and then recalled from memory to be converted into a specific response. Any time a vehicle operator receives information regarding the desired and actual state of his vehicle either directly or via displays and visual aids and adjust a control to regulate his task - he is performing tracking task.

One of the interesting aspects of tracking task is the various methods of measurements of useful parameters. A few of such methods are:

(1) Frequency of steering wheel reversals within given time.

(2) Lateral displacement of a vehicle from the reference point.

(3) Optimal use of brake, gas and gears.

(4) Ability of a driver to be on target (TOT or Time on Target Method, alternatively Time off Target may also be used).

(5) Zero crossing method.

(6) Tracking scores.

Scientists have used several methods, depending on the manner of the studies conducted. A quantity commonly recorded is the number of times the steering wheel is moved across the zero angle position. Frequency characteristics of a steering wheel control movements have been used by a number of authors as driving performance. Time on target or time within tolerances is an easy measurement to make and is the one which obviously correlates well with independent variables reflective of tracking skill. Cross over frequency is more appropriate for straight tracking. The one which is suitable for curved path is the measurement of lateral displacement of the vehicle from zero position.

2.2 WHY SIMULATOR?

Questions have been raised on the validity of using a simulator in order to study the parameters which are experienced in real life situations. We must not forget the fact that man is a creature whose output is totally stochastic and very seldom can be predicted accurately. Therefore, modeling the system becomes a tremendous challenge if an attempt is made to define the system in its entirety. The nature of the simulator design depends primarily on the uses to which they are to be tested. From the standpoint of this thesis the interest in simulation arises solely from a desire to subject certain aspects of driving to study under laboratory conditions. Although a number of draw backs can be cited against the simulator study, its advantages are equally valuable. Since human beings are involved, even a minor physical and emotional disturbance can cause measurable variations in driver actions. A simulator is particularily useful to repeat the environmental conditions as many times as the study required. Also using a simulator, it is possible to filter out unwanted conditions or make unnecessary parameters constant. In fact, simulator is the most suitable answer for a study such as this one.

A quick retrospect would reveal the necessity of quantitative study on the response time of a driver while exposed to road noise. Therefore, it is the purpose of this quantitative study to draw some useful conclusions on the effect of road noise on the response time of a driver.

CHAPTER THREE

EXPERIMENTAL SET UP - THE SIMULATOR

The entire experiment has been conducted in a Simulator, the basic description of which is given in reference 15. However, this has been greatly modified in concept and redesigned by the author. Also, the entire simulator except the half-car, the screen, and the projector has been built by the author. The simulator, consisted of the following;

1. Half Car
2. Rear projection screen.
3. Projector, road film and a turntable.
4. Mechanical direction selector
5. Electronic control circuits
6. Tape recorder and recorded road noise.
7. Sound level meter.
8. Multipen strip chart recorder

3.1 THE HALF CAR (Fig. 8) (For Fig. 1-8 see appendix F)

The front half of a car, (without engine) was inserted half the way through one of the two open ends of a wooden box which was kept at one end of a room. A dark cloth hanging from the top of the box, over the sides of the half car was used to minimize subjects distractions while performing task.

3.2 THE SCREEN (Fig. 8)

A 5' x 4' rear projection screen, mounted on two adjustable side supports was placed inside the box, close to the front bumper of the half car, so that it was in full view of the subject who was seated inside the half car.

3.3 PROJECTOR, ROAD FILM, AND THE TURN TABLE (Fig. 6)

A 16 mm, Bell & Howell, Model 173, Auto-Manual type projector was located about 24 ft. from the screen. The speed of the projector was varied by means of a speed control knob attached to the projector.

A 500 ft., 16 mm. colour movie film of a road was shot by the author from the top and directly behind the driver of a motor vehicle, so that the full view of the road travelled was captured, just as the driver saw it.

The turn table, designed and built by the author, consisted of two circular discs, connected by a steel rod through their centres such a way that the top disc, called the turn table, rotated freely with the bottom disc fixed firmly to a wooden platform.

The projector was placed on top of the turn table which could be rotated both directions either through a programmer by the experimenter or using the steering wheel by the subject. Connected to the turn table, through a gear combination of speed ratio of 100:1, was a speed reducer motor whose direction of rotation was the same as that of the turn table. The motor was attached to an aluminum base.

3.4 MECHANICAL DIRECTION SELECTOR (Fig. 7)

The mechanical direction selector designed and built by the author consisted of a stationary part attached to the body of the car, and a rotating part attached on to the gear box of the steering wheel. The stationary part was made up of sheet metal 2 inches wide, 6 inches long bent to the shape of an arc of radius 5 inches. Two 6v lamps, powered directly from the mains, through a transformer, were fitted in two holes provided at both ends of the stationary part.

Opposite to the lamps, along the same line, were two CL 907 photo cells which energized when light fell on them. The rotating part was a sheet metal piece, 2 inches wide, 4 inches long, also bent to an arc of radius 5 inches (approximately) was fixed such a way that when the steering wheel was turned, it moved freely in between the lamps and photocells. The moving part could only block one lamp-photocell combination at any one time. The rotating part which was connected to the gear box will rotate 270 degrees end to end for 4 1/2 steering wheel revolutions. Thus for one revolution of the steering wheel an angle of 60 degrees was rotated.

3.5 ELECTRONIC CONTROL CIRCUITS

The Electronic part of the system consisted of:

- i. Power Supply (Fig. 3)
- ii Pulse Indicator Circuit (Fig. 5)
- iii Recorder Pen Control Circuit (Fig. 4).
- iv Relay Control Circuit (Fig. 2)

v Motor Control Circuit

vi Lamp Circuit (Fig. 2)

A power supply was designed to supply 12v d.c. to the relay control circuit. A step-down transformer reduced the main voltage (120v) to a lower a.c. value which subsequently converted to 12v d.c. by means of a bridge and capacitor circuit. A reference diode was provided in order to keep a steady out put.

The pulse indicator circuit was arranged to provide a synchronous pulse to the recorder whenever a side shift was applied to the motor. This was an ordinary resistor-capacitor charge-discharge circuit. In order to avoid the conditioned response of an individual, if only one side shift was given, two side shifts of distinct magnitudes were applied randomly to the projector.

The recorder pen control circuit was to attenuate the large output signal produced by turning the steering wheel and to feed a proportional quantity of it to the recorder pen. The 10 turn, 10 K potentiometer was used to select any desired value. (In order to guarantee an uninterrupted test period, a battery of 8.4v and a zener diode of 3v were used). This low voltage zener and high voltage battery ensured a reliable long term operation of the circuit.

The purpose of the relay control circuit was to respond to the condition of photocells and to control the operation of the relays P and Q, as shown in Fig. 2. Initially when both lamps lighted and the rotating part of the mechanical direction selector at normal position both relays operated. When any one of the photocells was blocked from light, the corresponding relay released providing a path for the motor to turn to left or right determined by the released relay.

The essential part of the motor control circuit was a rectifier to provide 115v d.c. to a standard SCR controlled motor speed control circuit. The field of the motor was connected directly to 115v d.c. supply. The armature of the motor was connected through a set of relay-key contacts to the 115v d.c. supply, which also energized the SCR control circuit. The purpose of the relay-key contacts were to choose directions of turn of the motor either manually or by the subject using the steering wheel. A parallel combination of resistors and key contacts, serving as a programmer, to provide side shift movements to the projector were connected across the speed control potentiometer. A delay relay ensured delayed operation of the rectifier circuit in order to prevent a momentary short. Lamp L in Fig. 2 indicated the state of the circuit.

The lamp circuit is a small step down transformer, 120.6 volts a.c., and a parallel combination of two 6v lamps connected across it in such a way that when the main switch SW operates both lamps light. If the rotating part of the mechanical direction selector was at normal position, the photocells were energized.

3.6 ROAD NOISE AND TAPE RECORDER

Actual road noise of trucks, cars, buses and motorcycles were recorded by the author from a car running at 30 mph, with microphones kept at ear level of the driver. A pre-determined signal of known frequency and db level was placed at the beginning of the tape for calibration purposes. This tape was played back on a stereo tape recorder kept inside the experimental car, at three db levels of SPL (see Appendix A) of noise, N1=80, N2=90, N3-100. A separate record of average noise levels produced by a number of vehicles also taken from a parked car is given in Appendix B.

3.7 SOUND LEVEL METER

A Bruel and Kjoer type 2204 sound level meter kept at a distance the same as the subjects' ear from the tape recorder speaker measured the SPL of the noise; a proportionate value of which is fed to the multipen recorder.

3.8 MULTIPEN RECORDER (Fig. 8, Component 5)

A four pen, Rikadenki Multipen Recorder recorded:

1. The magnitude and time of steering wheel reversals
2. Side shift pulses.
3. The road noise.

A chart speed of 15 cm/min was used normally. Appendix E gives a number of chart samples and details of the recordings.

Since the aim of the study was to investigate the effects of road noise on driver performance behaviour it was considered necessary that the persons holding driver's licences issued by the Department of Transportation, Province of Ontario, be allowed to participate in the experiment.

22 subjects were selected randomly, both men and women of different ages and having varying driving experiences. They include office workers, technicians, machine operators and executives. Particulars of subjects' age, sex, driving experience etc. are given in Table 1.

TABLE 1

INFORMATION OF SUBJECTS

	SUBJECT	AGE	DRIVING EXPERIENCE Yrs.	(Miles)	SEX	PROFESSION
1	R.C.	28	8	(40,000)	M	Student
2	J.S.	27	8	(65,000)	M	Motor Mechanic
3	F.D.	26	10	(80,000)	M	Office Clerk
4	P.F.	47	20	(150,000)	M	Technician
5	M.G.	34	18	(120,000)	M	Professor
6	W.B.	26	9	(50,000)	M	Student
7	R.G.	26	10	(40,000)	M	Student
8	N.G.E.	48	25	(500,000)	M	Professor
9	M.G.E.	50	34	(90,000)	F	Housewife
10	L.C.	43	31	(300,000)	M	Executive
11	V.V.J.	32	10	(70,000)	M	Office Clerk
12	B.S.	22	6	(45,000)	M	Technician
13	E.O.	34	88	(80,000)	M	Executive
14	E.A.M.	28	2	(10,000)	M	Student
15	Y.Q.	22	4	(15,000)	F	Nurse

TABLE 1 (Cont'd.)

INFORMATION ON SUBJECTS

	SUBJECT	AGE	DRIVING EXPERIENCE YRS.	(Miles)	SEX	PROFESSION
16	S.P.I.	28	9	(48,000)	M	Research Assistant
17	B.C.	35	9	(90,000)	F	Secretary
18	S.W.	27	10	(250,000)	M	Technician
19	W.B.	36	19	(175,000)	M	Technician
20	L.D.	23	7	(45,000)	M	Student
21	E.B.	24	7	(50,000)	M	Student
22	R.D.	29	10	(80,000)	M	Technician

CHAPTER FOUR

4.1 EXPERIMENTAL PROCEDURE AND METHODS OF DATA COLLECTION

Prior to the experiment a brief explanation on the experimental set up and procedure to be followed was explained to each subject and a 10 minute warm-up was given to get adjusted with the set up. Then the experimenter randomly selected:

1. A speed level (S_1 = 30 m.p.h. or S_2 = 40 m.p.h. or S_3 = 50 m.p.h.)
2. A noise level (N_1 = 80 db or N_2 = 90 db or N_3 = 100 db.)
3. A side shift (SS_1 = 1.5 ft/sec or SS_2 = 2.5 ft/sec)

All noise levels and speed levels were varied randomly during the course of experiment so that all combinations of speed and noise were selected. During the experiment side shifts were applied randomly to the projector by the experimenter so that the subject would see the road moves to one direction. The task of the driver was to react to the side shifts and bring the car again on the road. Three replications were made for each experimental conditions and a higher chart speed (60 cm/min), other than the normal one (15 cm/min), was used for all replications. Meanwhile, a tape recorder replayed the road noise inside the car and its sound pressure level (SPL) was measured by a precision sound level meter and was recorded by the multipen strip chart recorder. The potentiometer connected to the steering wheel transferred any movement of it to the multipen strip chart recorder.

When the experimenter applied the side shift to the road, a simultaneous pulse which indicated the time of input pulse was sent to the strip chart recorder, on observing the side shift of the road the subject tried to bring it back to the centre of the screen by manipulating the steering wheel. The steering wheel movement sent a pulse to the recorder. The difference between the initiation of thr side shift and the initiation of the steering wheel manipulation was taken as performance time. The Performance Time as defined is assumed to be the indicator of the driver's performance.

The experiment lasted about 1 to 1-1/4 hours, with two 5 minute breaks in order to rewind and re-arrange film and tapes.a The normal chart speed used for the experiment was 15 cm/min. Later this chart was analyzed and performance time measurements were made.

4.2 DATA COLLECTION

All necessary information such as the side shift initiation and magnitude, steering wheel initiation and magnitude, and noise levels were recorded by the Multipen Strip Chart recorder. The chart contained, for each subject, three noise levels, three speed levels, two side shifts and three replications of the above conditions. The data collected for each subject under each experimental conditions are given in Table 2. These are the performance times measurements taken from each Subject's Chart. Performance time las been taken from the charts as the time between initiation of the side shift pulse to the moment the subject responded to it. There are 54 such measurements for each subject, for 3 noise levels, 3 speed levels, and 2 side shifts with 3 replications. These data were analysed using a statistical technique called Analysis of Variance (ANOVA) and its details are given in Chapter 5. Graphs between noise levels and performance time for each individual are given in Appendix H.

Figures 9, 10 & 11 show the driver response, noise levles and side shifts as they were recorded by the multipen strip chart recorder. A speciman measurement of how performance time was determined is also shown.

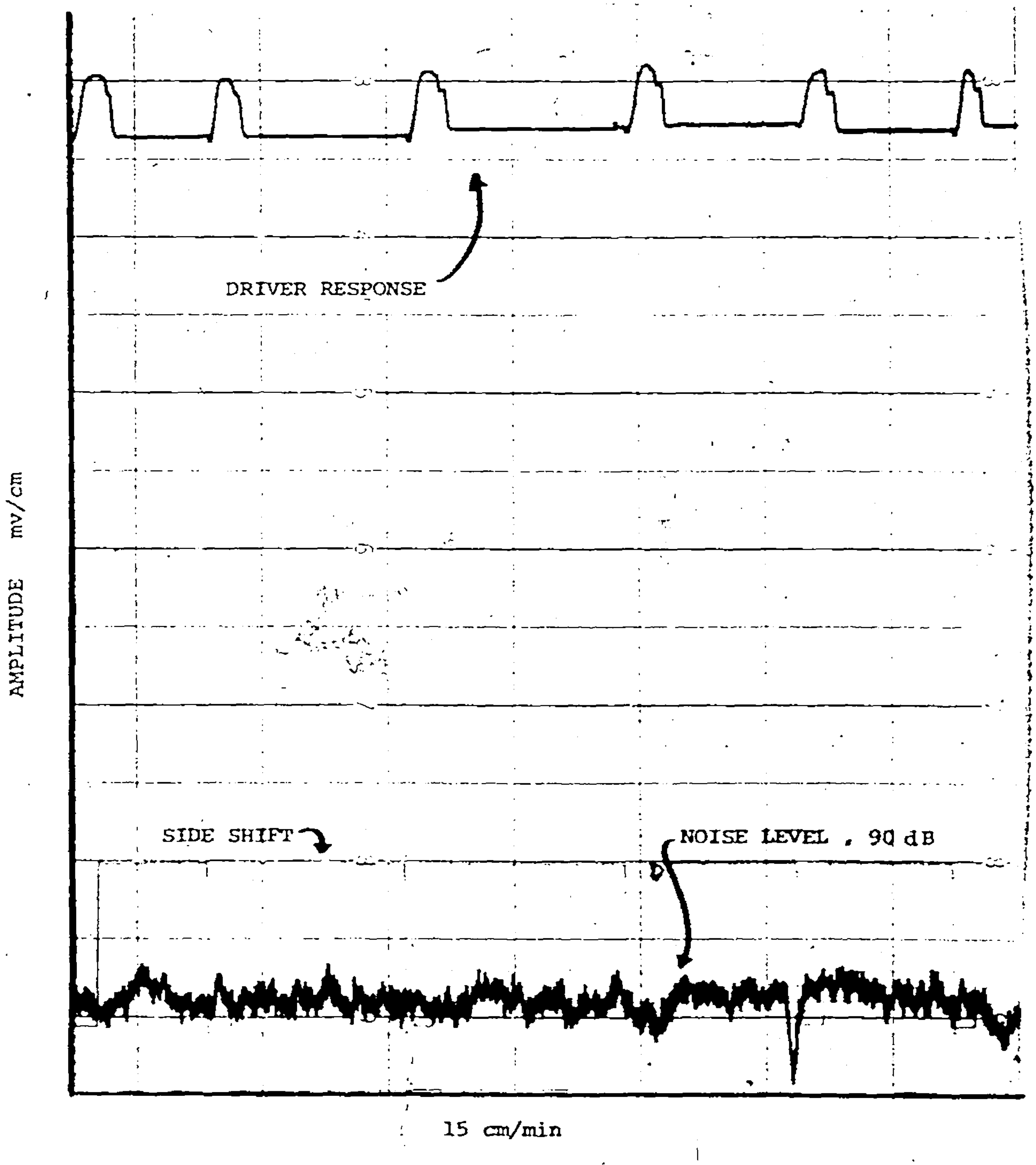
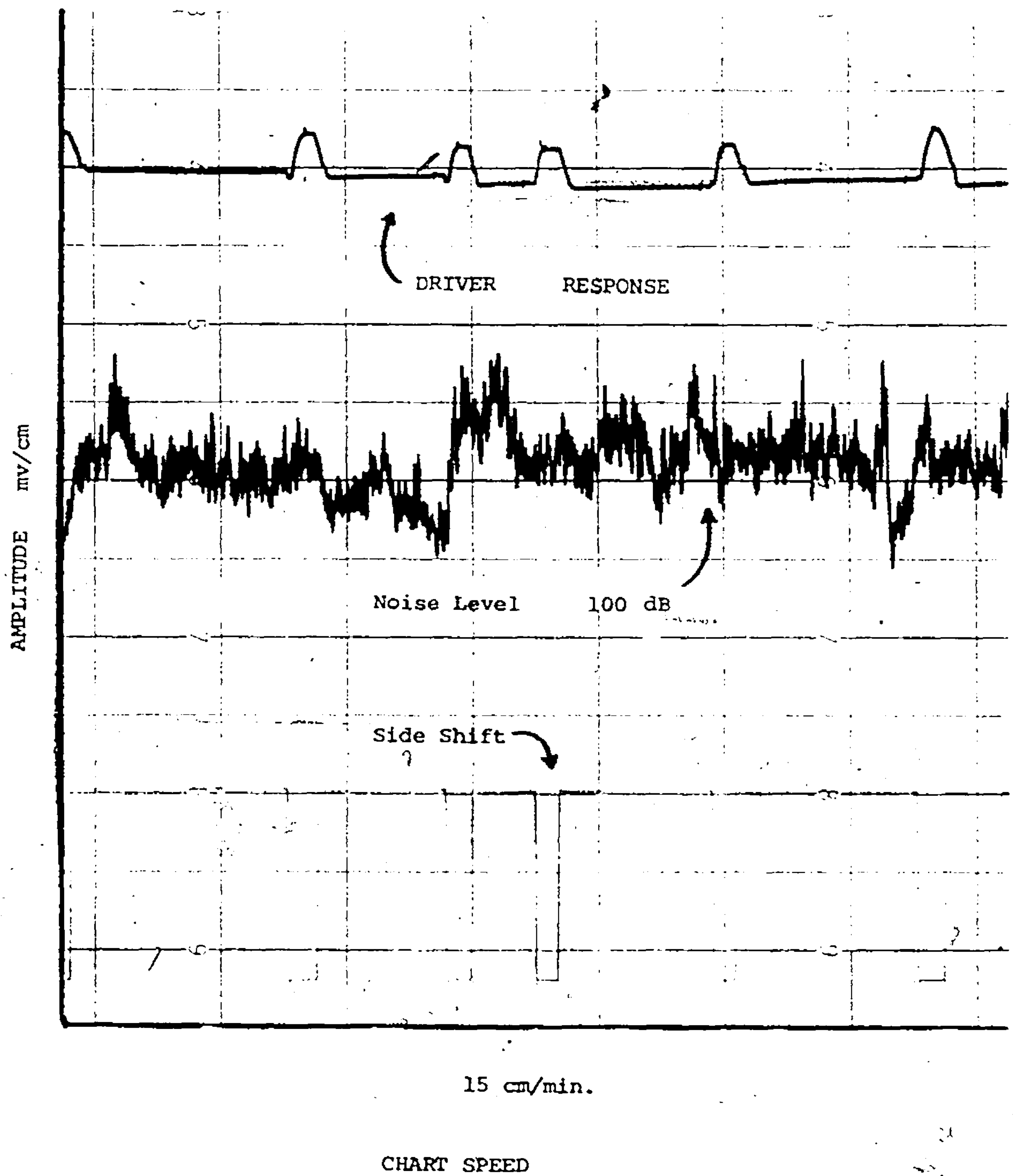

DRIVER RESPONSE
AMPLITUDE mv/cm
SIDE SHIFT
NOISE LEVEL , 90 dB
15 cm/min
CHART SPEED

Figure 9



DRIVER RESPONSE
Noise Level 100 dB
Side Shift
AMPLITUDE mv/cm
15 cm/min.
CHART SPEED

Figure 10

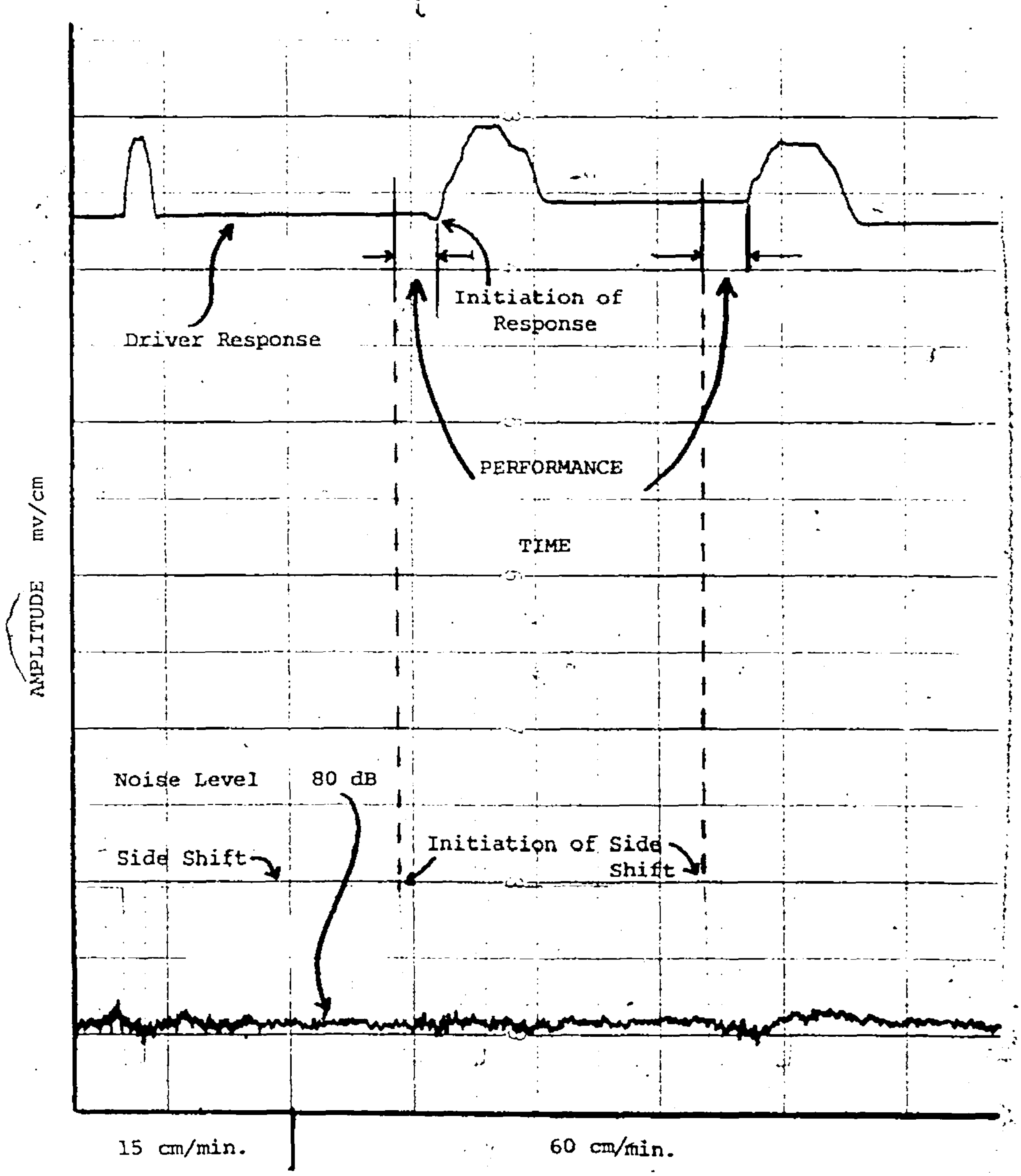


CHART SPEED

FIGURE 11

TABLE 2

PERFORMANCE TIME MEASUREMENTS

		N1			N2			N3		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
W.B.	R1	1.024	1.104	0.744	1.064	1.020	1.100	1.060	0.894	1.064
	R2	0.984	1.104	0.904	1.060	0.886	0.984	1.016	0.946	0.826
	R3	0.823	1.024	0.756	1.024	0.816	0.956	0.984	0.866	1.040
	R1	0.663	1.184	0.886	0.663	1.006	0.864	1.010	1.024	0.884
	R2	0.944	1.024	0.904	0.928	0.986	0.944	1.126	1.104	1.064
	R3	1.024	1.024	0.784	0.946	0.984	0.976	0.996	1.020	0.944
R.C.	R1	1.304	0.690	0.696	0.824	0.901	0.904	0.944	0.864	1.104
	R2	1.024	0.684	0.676	0.904	0.820	0.824	1.144	0.784	0.824
	R3	1.040	1.020	0.944	0.744	0.824	0.864	1.064	0.724	0.824
	R1	1.460	0.904	0.864	0.880	0.856	0.816	1.004	0.904	1.140
	R2	0.820	0.864	1.024	0.940	0.804	0.836	0.904	0.826	0.916
	R3	0.984	1.184	0.984	0.864	0.940	0.984	0.836	1.104	1.060
E.O.	R1	1.184	1.124	1.044	1.056	0.998	0.968	0.866	1.024	1.124
	R2	0.904	0.830	0.966	0.966	1.006	0.706	0.926	1.026	0.926
	R3	1.124	1.024	0.988	1.060	0.966	0.904	0.926	1.144	1.144
	R1	1.080	1.064	1.184	0.824	0.920	1.060	1.146	1.040	1.184
	R2	0.836	1.024	1.060	1.264	1.304	1.304	1.304	1.264	1.264
	R3	1.024	0.684	0.676	0.904	0.820	0.824	1.144	0.784	0.824
E.B.	R1	0.784	1.144	1.024	0.824	0.666	0.664	0.904	0.944	1.024
	R2	0.772	0.864	1.224	0.824	0.686	0.996	1.064	1.144	1.184
	R3	0.746	0.864	1.224	0.744	0.856	1.024	0.986	0.956	0.866
	R1	0.784	0.724	0.776	0.664	0.664	1.034	0.784	1.084	1.024
	R2	0.772	0.664	0.756	0.804	0.664	0.966	0.746	0.796	1.024
	R3	0.746	0.984	1.046	0.744	0.656	1.064	0.656	1.084	1.304
W.B.	R1	0.882	0.916	1.046	1.064	0.976	0.904	1.226	1.000	1.064
	R2	0.904	0.836	0.966	0.966	1.006	0.706	0.926	1.026	0.926
	R3	0.886	0.904	1.806	1.021	1.024	0.956	0.946	1.064	0.816
	R1	0.846	0.672	0.716	0.856	0.756	0.984	1.306	0.906	0.846
	R2	0.984	0.876	0.986	0.946	0.766	0.872	1.166	1.076	0.836
	R3	0.944	0.784	0.696	0.766	1.024	0.786	1.064	0.966	1.024

TABLE 2 (Cont'd.)

		N1			N2			N3		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
N.G.E.	R1	1.224	1.222	1.144	0.704	0.826	0.706	0.636	1.064	0.824
	R2	0.744	1.264	0.984	0.664	0.718	0.916	0.716	0.756	0.886
	R3	1.264	1.184	1.264	0.744	0.710	0.876	1.064	0.886	0.736
	R1	0.944	1.024	1.184	0.984	0.784	0.682	0.984	0.784	0.866
	R2	1.104	1.064	1.344	0.664	0.784	0.986	0.864	0.784	0.726
	R3	1.104	0.744	1.104	0.864	0.784	0.784	1.264	0.664	0.916
R.G.	R1	0.924	0.932	1.104	0.940	0.894	0.784	0.530	0.664	0.424
	R2	0.903	0.921	0.944	0.864	0.864	0.682	0.510	0.612	0.664
	R3	0.901	0.874	1.186	0.850	0.872	0.651	0.540	0.601	0.632
	R1	0.100	1.220	1.180	0.784	0.816	0.704	0.654	0.424	0.664
	R2	0.920	0.928	1.020	0.820	0.820	0.820	0.662	0.435	0.676
	R3	0.904	0.874	1.120	0.760	0.810	0.924	0.581	0.543	0.624
N.G.E	R1	0.696	1.270	1.180	1.040	0.970	1.040	0.944	0.688	0.922
	R2	0.884	1.140	1.100	1.320	0.980	1.070	0.684	0.684	1.180
	R3	0.704	1.200	1.140	1.160	0.880	1.130	0.670	0.688	0.904
	R1	1.060	0.840	1.010	0.924	0.924	1.070	0.920	0.696	0.676
	R2	0.892	0.980	1.240	0.984	0.938	1.050	0.676	0.682	0.686
	R3	0.731	0.800	0.980	0.968	0.955	1.020	0.686	0.696	0.688
M.G	R1	1.064	0.864	0.966	0.984	0.744	0.744	1.144	0.904	0.984
	R2	1.064	0.664	0.904	0.664	0.966	0.680	1.024	0.944	1.376
	R3	1.024	0.764	0.834	0.984	0.926	0.830	1.154	1.064	1.124
	R1	0.984	1.064	0.744	0.824	0.704	0.864	0.904	0.984	0.944
	R2	0.916	0.966	0.944	0.924	0.704	0.660	1.224	0.864	0.660
	R3	0.924	0.988	0.944	0.904	0.724	0.726	1.264	0.944	0.784
B.C	R1	1.024	0.986	0.824	0.704	0.744	0.904	1.024	0.944	1.020
	R2	1.064	0.966	0.904	0.664	0.624	0.704	0.824	0.986	1.124
	R3	1.024	1.060	1.064	0.664	0.704	0.704	0.866	0.866	1.024
	R1	0.944	1.104	0.824	0.744	0.904	0.704	1.064	0.704	0.904
	R2	1.104	1.184	0.744	0.704	0.904	0.704	0.744	0.744	0.744
	R3	0.904	1.024	0.744	0.664	0.624	0.664	0.704	0.704	0.784

TABLE 2 (Cont'd.)

		N1			N2			N3		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
S.W.	R1	0.864	0.904	1.144	0.752	0.696	1.060	1.020	0.824	0.944
	R2	0.944	1.064	1.344	0.820	0.698	0.906	0.986	0.726	0.934
	R3	0.864	1.380	1.020	0.940	0.944	0.944	1.284	0.904	0.950
	R1	1.080	1.204	1.220	0.824	0.824	0.920	1.146	1.060	1.000
	R2	1.060	1.024	0.984	0.734	0.784	1.060	1.040	0.904	0.824
	R3	1.020	1.120	1.280	0.782	0.810	0.956	1.120	0.884	0.936
S.P.I.	R1	1.104	1.184	0.904	0.864	1.064	0.784	1.304	1.024	1.404
	R2	1.384	0.984	0.784	1.144	1.064	0.824	1.024	1.024	1.344
	R3	1.064	1.024	0.984	1.064	1.104	1.024	0.904	1.184	1.204
	R1	0.984	0.944	1.064	0.824	0.944	0.784	1.144	1.064	1.104
	R2	0.864	0.864	1.064	1.064	0.864	0.904	1.384	1.264	1.384
	R3	0.984	0.944	0.864	1.144	0.824	0.784	1.244	1.144	1.024
L.C.	R1	1.740	1.180	0.944	0.884	0.904	0.784	1.064	0.904	0.904
	R2	1.144	1.160	0.904	0.904	0.864	0.940	0.986	1.064	0.984
	R3	1.424	1.220	1.020	0.980	0.724	0.904	0.904	0.864	1.224
	R1	1.184	1.064	0.944	0.884	0.904	0.784	1.064	0.904	0.904
	R2	1.106	1.024	0.904	0.904	0.864	0.940	0.986	1.064	0.984
	R3	1.064	1.086	1.020	0.980	0.724	0.904	0.984	0.864	1.224
B.S.	R1	1.064	1.104	0.744	1.064	0.864	0.664	0.864	1.224	1.204
	R2	0.864	0.864	1.144	0.904	0.744	0.904	1.024	1.144	1.064
	R3	0.904	0.824	1.184	0.944	0.744	0.704	0.944	0.866	1.244
	R1	0.864	1.064	0.864	0.744	0.664	0.944	0.744	0.904	1.384
	R2	0.944	1.222	0.784	0.904	0.664	1.056	1.064	0.984	1.384
	R3	1.024	0.784	0.744	0.944	0.744	0.744	0.824	1.104	1.104
V.V.J.	R1	1.024	1.184	1.104	1.104	1.024	0.864	1.184	1.144	1.304
	R2	1.224	1.184	1.264	1.164	0.864	0.864	1.024	1.224	1.304
	R3	1.024	1.184	1.264	1.064	1.184	0.984	1.144	1.264	1.384
	R1	1.184	1.104	0.984	0.864	1.024	0.944	1.104	0.084	1.224
	R2	1.144	1.144	1.024	0.864	0.944	0.944	1.104	1.104	1.064
	R3	1.064	1.184	1.024	1.184	0.864	0.824	1.024	1.184	1.184

Table 2 (Cont'd.)

		N1			N2			N3		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
E.A.M	R1	1.024	0.684	0.676	0.904	0.820	0.824	1.144	0.784	0.824
	R2	0.784	1.144	1.024	0.824	0.666	0.664	0.904	0.944	1.024
	R3	1.024	1.184	1.264	1.064	1.184	0.984	1.144	1.264	1.384
	R1	1.080	1.204	1.220	0.824	0.824	0.920	1.146	1.060	1.000
	R2	0.823	1.024	0.756	1.024	0.816	0.956	0.984	0.866	1.040
	R3	0.944	1.064	1.344	0.820	0.698	0.906	0.986	0.726	0.934
F.D	R1	0.744	0.626	1.484	0.984	0.864	0.916	0.986	0.666	0.904
	R2	0.944	0.944	0.904	0.944	0.744	0.896	0.996	0.744	0.916
	R3	1.064	0.664	1.026	0.966	0.676	0.816	0.864	0.704	0.784
	R1	1.058	1.060	0.824	0.716	0.664	0.744	0.866	1.024	1.184
	R2	1.028	1.064	0.904	0.696	0.864	0.744	0.936	1.064	1.084
	R3	1.060	1.124	0.944	0.716	0.744	0.646	1.024	1.024	1.266
P.F	R1	1.304	1.264	1.180	1.500	1.360	0.944	1.064	1.264	1.304
	R2	1.264	1.064	1.264	1.540	1.224	1.184	1.064	1.184	1.024
	R3	1.266	1.180	1.080	1.340	1.380	1.230	1.144	1.024	1.220
	R1	1.100	1.304	1.264	1.424	0.984	1.064	1.544	1.184	1.184
	R2	1.069	1.124	1.160	1.384	1.024	1.144	1.064	1.264	1.064
	R3	0.836	1.024	1.060	1.264	1.304	1.304	1.304	1.264	1.264
Y.Q	R1	1.124	0.984	1.098	0.796	0.836	0.904	0.948	0.980	1.068
	R2	1.108	1.064	0.866	0.966	0.744	0.904	0.986	1.020	1.128
	R3	1.234	1.184	1.064	0.866	0.784	0.944	0.886	1.060	1.120
	R1	1.112	1.040	0.986	0.866	0.744	0.886	0.904	1.068	1.230
	R2	1.238	1.084	0.866	0.904	0.866	0.944	0.948	1.020	1.180
	R3	1.130	0.988	1.060	0.904	0.836	0.836	0.986	1.120	1.105
R.D	R1	0.896	0.966	0.826	0.766	0.726	1.133	1.166	0.806	0.936
	R2	0.926	1.216	1.066	0.776	0.776	1.056	1.076	0.786	0.736
	R3	0.896	1.236	1.056	0.736	0.886	1.220	1.026	0.956	1.216
	R1	1.200	0.866	1.156	0.776	0.886	1.246	0.866	0.966	0.956
	R2	1.166	1.046	0.786	0.786	0.926	1.066	1.046	1.366	0.916
	R3	1.066	0.886	1.296	0.716	0.826	1.196	0.816	0.916	0.886

TABLE 2 (Cont'd.)

		N1			N2			N3		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
L.D.	R1	1.264	0.606	0.904	0.744	0.664	0.744	1.184	1.184	1.467
	R2	1.104	0.706	0.864	0.704	0.744	0.744	1.384	1.424	1.184
	R3	1.064	0.664	0.944	0.906	0.784	0.784	1.584	1.464	1.536
	R1	0.904	0.784	0.904	0.984	0.864	0.664	0.864	1.224	1.104
	R2	1.144	1.144	0.664	0.784	0.944	0.704	0.904	1.224	0.904
	R3	0.984	0.944	0.664	0.904	0.664	0.664	0.904	0.904	1.464
J.S.	R1	0.904	0.784	0.824	0.984	1.064	1.024	0.904	1.224	1.544
	R2	0.984	0.984	0.864	0.784	0.984	1.144	1.184	1.264	1.504
	R3	0.984	0.744	1.064	0.864	0.984	0.904	0.944	1.064	1.504
	R1	1.240	0.944	0.744	0.784	0.864	1.064	1.024	1.224	1.224
	R2	1.084	0.864	0.864	0.766	0.904	1.104	0.944	1.064	1.128
	R3	0.986	0.984	0.904	0.784	0.944	0.984	1.064	1.108	1.108

CHAPTER FIVE

ANALYSIS OF DATA

In order to analyse the measurements which depended on both noise and speed effects operating simultaneously and to decide and estimate which kind of effect was predominant, a statistical technique called Analysis of Variance (ANOVA) was used. The following reasons also found to be advantageous in choosing this technique.

1. It is a convenient method of evaluating by a simple test, called F-test, the overall differences among the means of several experimental groups. The F-test involved in finding the ratio of two variances which, if a stated null hypothesis were true, would fall inside a specified point of the appropriate F-distribution. If this variance ratio falls beyond the 5 per cent point of F-distribution, known as confidence limit, determined by degrees of freedom of the two variances concerned, then the null hypothesis is rejected at the 5 per cent level of significance.

2. It provides means of avoiding errors of interpretation due to the complexities of probabilities when a number of means are to be compared.

The fundamental equation for Analysis of Variance is that the total sum of squares of deviations from grand mean is equal to the sum of squares of deviations between treatment means and the grand mean plus the sum of squares of deviaitions within treatments.

Following model was used to analyse the data given in Table 2:

$$X_{ijk} = \mu + \alpha_i + \beta_j + \alpha\,\beta_{ij} + \varepsilon_{ijk}$$

$$i = 1, 2, 3$$

$$j = 1, 2, 3$$

$$k = 1, 2, 3 \quad \text{(replication)}$$

where X_{ijk} is the mean performance time for ith speed level, jth noise level and kth replication. μ is the general mean, α is the effect of speed, β is the effect of noise, $\alpha\beta$ is the interaction between speed and noise, and ε_{ijk} is an independent chance component, representing error in the experiment, with normal distribution $N\ (0,\sigma)$.

The null hypothesis tested were:

$$\Sigma\ \alpha_i = 0$$

$$\Sigma\ \beta_j = 0 \quad \text{and}$$

$$\Sigma\Sigma\ \alpha\beta_{ij} = 0$$

A 5 per cent confidence level is choosen in order to accept or reject the null hypothesis for this analysis α and β were treated as fixed level.

A standard computer program used to analyse the data and all computer outputs are given in Appendix G. Table 3 lists F-ratios of noise effects, speed effects and noise-speed interaction effects. All significant effects as compared with standard tables for α=0.05 are marked by *. Per cent rise of performance time of each subject is also given in Table 3. The increase in performance times have been calculated between lowest and largest performance times recorded while the levels of noise increased.

The method of how per cent rise in Performance Time is calculated is shown below.

$$\text{Percent rise in performance time for a subject} = \frac{A - B}{B} \times 100$$

where A = Maximum Performance Time

B = Minimum Performance Time

All subjects except W.B. and R.D. (Table 3) have indicated to have higher noise effect, showing that noise produces an incremental effect in their performance time. This is also evident from the per cent rise in performance time listed in table 3 and the respective graphs given in Appendix H.

Subjects WB and RD did not show the noise effect to be a significant level. On further investigation it was revealed that these subjects have been exposed to noisy industrial environments for a minimum period of 5 years.

Table 3 also indicates that 60% of the subjects show significant noise-speed interaction. This is also evident from the graphs provided in Appendix H.

It should also be noted, from Table 3, that the per cent rise in Performance Time varies between 19.41% to 58.42%, meaning the effect of noise varies from subject to subject.

Correlation coefficient determined between age, driving experience vs Performance Times of all subjects indicate that they are all insignificant ($\alpha = 0.05$).

CHAPTER SIX

FINDINGS AND CONCLUSIONS

6.1 Findings

Experimental results indicate that noise does affect subjects performance time as shown in Table 3. Statistical results show that noise effect is high for 80% of the subjects whereas 10% have higher speed effect and 10% shows higher noise speed interaction.

It is also evident from Appendix H that the increase of performance time at different levels is different for different subjects.

Other observations from the results and on the subjects while performing experiment are:

(a) Performance Time varies among subjects.

(b) For most of the subjects, large variation of performance times occured during higher noise levels.

(c) F-ratios as given in Table 3, show that for 10% of the subjects tested, speed effect was higher than the noise effect, meaning speed is the major factor effecting performance times.

(d) Performance Time, in general, is smaller for side shift of 1.5 ft/sec than for side shift of 2.5 ft/sec.

(e) As noise level increased some drivers showed increased alertness.

(f) Subjects who drive cars with power steering required a little longer time for adjusting to the system.

(g) All subjects remarked that noise did distract them during the experiment.

(h) Occasional slammings on brakes by the subjects were observed during the experiment especially when a subject came across a curve or an on-coming car.

6.2 CONCLUSIONS

Within the restrictions of present study the following conclusions can be made:

1. Noise is a significant factor for driver's performances.

2. Performance Times tend to be higher for experimental conditions having higher noise levels.

3. For drivers who were previously exposed to noisy industrial environments, noise is not a significant factor.

4. There is no correlation between the driver's experience and minimum performance time ($\alpha = .05$).

6.3 Suggestions for Further Study

It is suggested that effects of controlled environments on driver performance over longer period of time be investigated. An additional variable of road vibrations be also included in order to study driver fatigue.

TABLE 3

Effect of Noise ________ F-Ratio ($\alpha=0.05$) and % Rise in Performance Time

	SUBJECT	SIDE SHIFT	NOISE EFFECT	SPEED EFFECT	NOISE-SPEED INTERACTION	% RISE OF PERFORMANCE TIME
1	R.C.	1	5.818*	0.868	2.629	29.72
		2	10.982*	1.240	6.425	21.37
2	J.S.	1	12.414*	0.804	8.80*	22.35
		2	16.232*	5.729*	3.798*	29.79
3	F.D.	1	7.212*	1.062	1.408	41.12
		2	7.472*	2.093	9.02*	32.62
4	P.F.	1	5.087*	2.821	3.420*	42.8
		2	2.303	0.476	2.070	38.24
5	M.G.	1	10.636*	3.337*	2.324	34.82
		2	7.882*	6.844*	2.417	28.24
6	W.B.	1	2.206	1.462	1.236	19.41
		2	7.124*	3.437	1.402	19.41
7	S.P.I.	1	3.782*	0.619	4.318*	37.19
		2	16.837*	1.509	0.845	39.38
8	B.C.	1	35.374*	1.024	2.513	42.38
		2	11.057*	3.260*	3.633*	37.51
9	S.W.	1	41.958*	2.038	3.333*	37.22
		2	21.473*	1.346	4.623*	44.67
10	W.B.	1	0.836	1.896	5.508*	46.89
		2	2.377	4.197*	1.160	34.07
11	L.D.	1	6.652*	6.371*	3.484*	56.42
		2	5.616*	1.120	2.763	47.68
12	E.B.	1	6.355*	4.799 *	2.014	42.00
		2	11.624*	4.272*	2.821	47.43

TABLE 3 (cont'd.)

	SUBJECT	SIDE SHIFT	NOISE EFFECT	SPEED EFFECT	NOISE-SPEED INTERACTION	% RISE OF PERFORMANCE TIME
13	R.G.	1	75.102*	0.445	6.901*	58.42
		2	50.13*	16.685*	9.952*	42.16
14	N.G.E.	1	60.015*	0.956	0.347	42.44
		2	9.020*	3.391*	1.773	34.13
15	N.G.E.	1	16.420*	7.340*	10.982*	42.98
		2	22.675*	2.740	17.065*	36.71
16	L.C.	1	6.178*	3.206	4.012*	43.66
		2	8.990*	1.843	1.310	29.48
17	V.V.J.	1	13.623*	0.597	4.937*	36.87
		2	42.659*	0.117	3.335*	23.65
18	B.S.	1	6.795*	1.728	5.163	42.19
		2	6.088*	0.335	2.108	34.13
19	E.O.	1	4.701*	0.565	1.458	36.08
		2	5.868*	1.825	2.314	32.31
20	E.A.M.	1	6.920*	0.336	0.162	31.9
		2	5.120*	0.754	1.180	46.41
21	Y.Q.	1	22.940*	1.065	4.331*	27.11
		2	31.672*	0.871	9.585*	25.23
22	R.D.	1	1.7	1.82	4.25*	20.14
		2	2.14	2.35	6.56*	22.26

APPENDIX A

SOUND PRESSURE LEVEL

SOUND PRESSURE LEVEL (SPL)

Sound pressure level is the measurement of pressure change associated with vibration of air molecules. Sound pressure is, generally, expressed as number of decibels (dB) above some reference level. The pressure reference level most commonly used is 0.0002dynes per square centimeter. The formularfor calculating the number of decibels is

$$N_{dB} = 20 \log_{10} \frac{P1}{P0}$$

where P1 is the sound pressure to be measured and P0 is the reference pressure.

APPENDIX B

1. Some facts about noise

SOURCE	(dB) NOISE LEVEL
Reference level	0
Quiet office	40
Normal Conversation	60
Average automobile	70
Noisy auto	80
City Bus	90
Subway Trains	100
Twine Engine Airplane	110
Loud Thunder	120
Painful Sound	130

2. Some Noise Levels Recorded from a Parked Car

VEHICLE	NOISE LEVEL (dB)
City Bus	90-94
Automobile	84-86
Automobile (4 cylinder)	88-92
Sports CAr	90+
Motor Bike (Medium Size)	94-96
Pick up Trucks, Delivery Trucks	90-94
Small Delivery Wagons	86-88
Automobile Delivery Trucks*	100-105
Medium size load Trucks	100-104

*Measurement made at intersection showed a peak value of 110dB when the truck accelerated after a stop.

General observation is:

i. Higher the noise when the number of cylinders are less.

ii. Higher the noise when truck size (tonnage) increases.

3. How much noise we make?

Distance between Talker and Listener	Normal (dB)	Raised (dB)	Very loud (dB)	Shouting (dB)
1/2 ft.	71	77	83	89
1 ft.	65	71	77	83
12 ft.	43	49	55	61

APPENDIX C

SIDE SHIFT MAGNITUDES

(Taken from Ref. 44)

Front wheel angle (Degrees)

Car Speed	1.	2	3	4
30	0.76	1.54	2.13	
40	1.02	2.05	3.07	- (in Ft.)
50	1.28	3.56	--	

Analytical Method

Width of the Screen ....5 ft.

Speeds	Seconds	Shift (ft/sec.)
1	4.63	1.04
2	3.75	1.33
3	2.6	1.92

Side shift magnitude

1. 1.5 ft/sec
2. 2.5 ft/sec

APPENDIX D

QUESTIONNAIRE

1. Age

2. Driving Experience a. years b. Total Miles

3. Number of accidents

4. Fastest Speed (Max. Speed) Driven.

5. Type of steering wheel (Power or Manual) subject normally uses.

6. Name.

APPENDIX E

CHART SAMPLES

GUIDE TO CHART SAMPLES

GUIDE

Ni - Noise Level, N_1=80 db, N_2=90 db, N_3=100 db

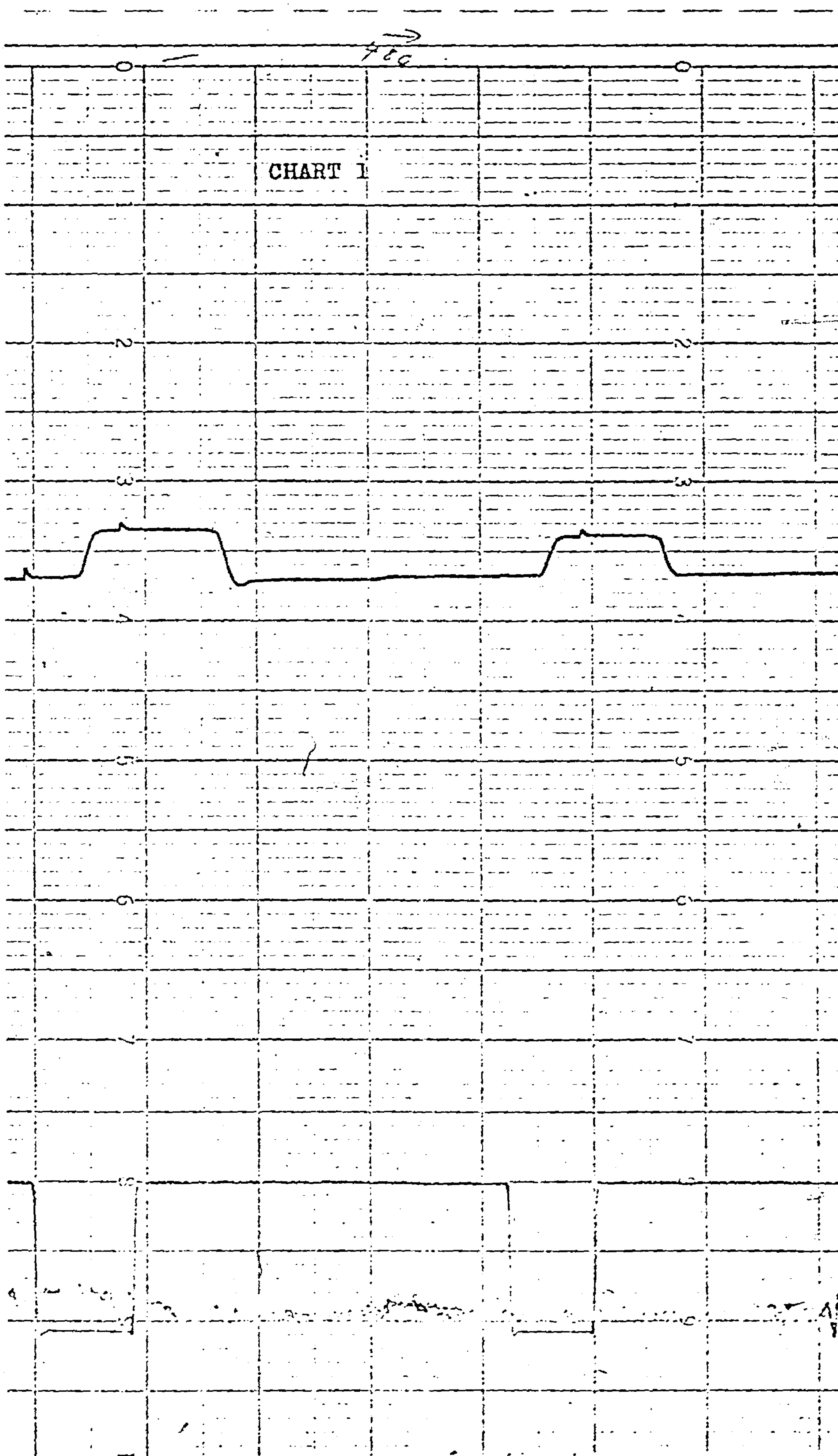
Si - Road Speed, S_1=30 mph, S_2=40 mph, S_3=50 mph

CSi - Chart Speed, CS_1=15 cm/min, CS_2=60 cm/min

SSi - Side Shift, 1 - 1.5 ft/sec. 2 - 2.5 ft/sec.

CHART	Ni	Si	Csi	SSi	REMARKS
1	N1	S3	CS2	1	These speciman
2	N3	S2	CS1, CS2	1	charts are taken
3	N1	S3	CS1, CS2	1	from outputs of
4	N1	S2	CS1	2	different subjects.
5	N3	S3	CS1	2	
6	N2	S2	CS1	1	
7	N3	S3	CS1	1	
8	N2	S3	CS1	2	
9	N3	S2	CS1	2	
10	N3	S1	CS1	2	
11	N2	S2	CS1	1	
12	N2	S3	CS1	1	
13	N1	S1	CS1, CS2	1	
14	N1	S3	CS2	1	
15	N3	S3	CS2	2	

CHART 1



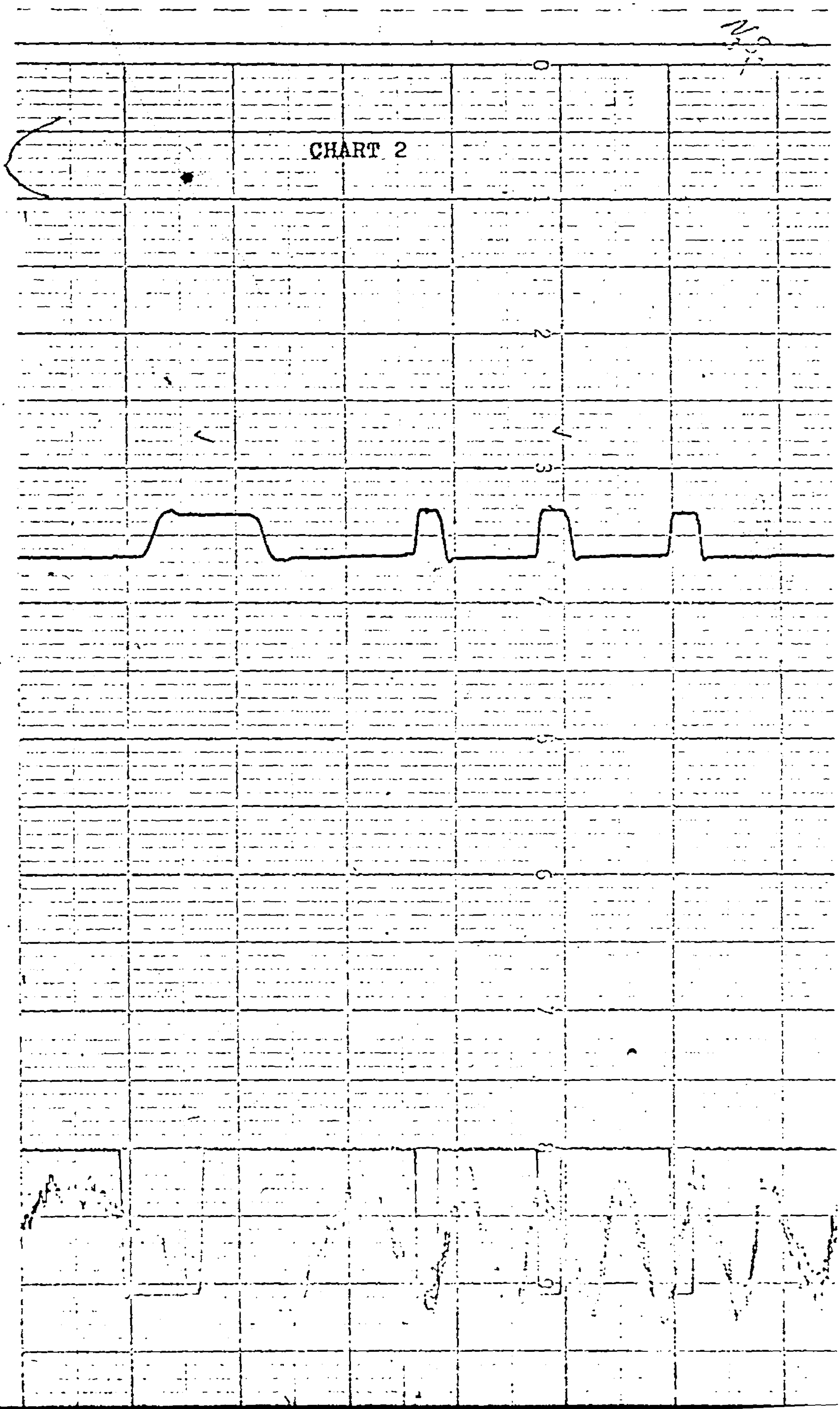
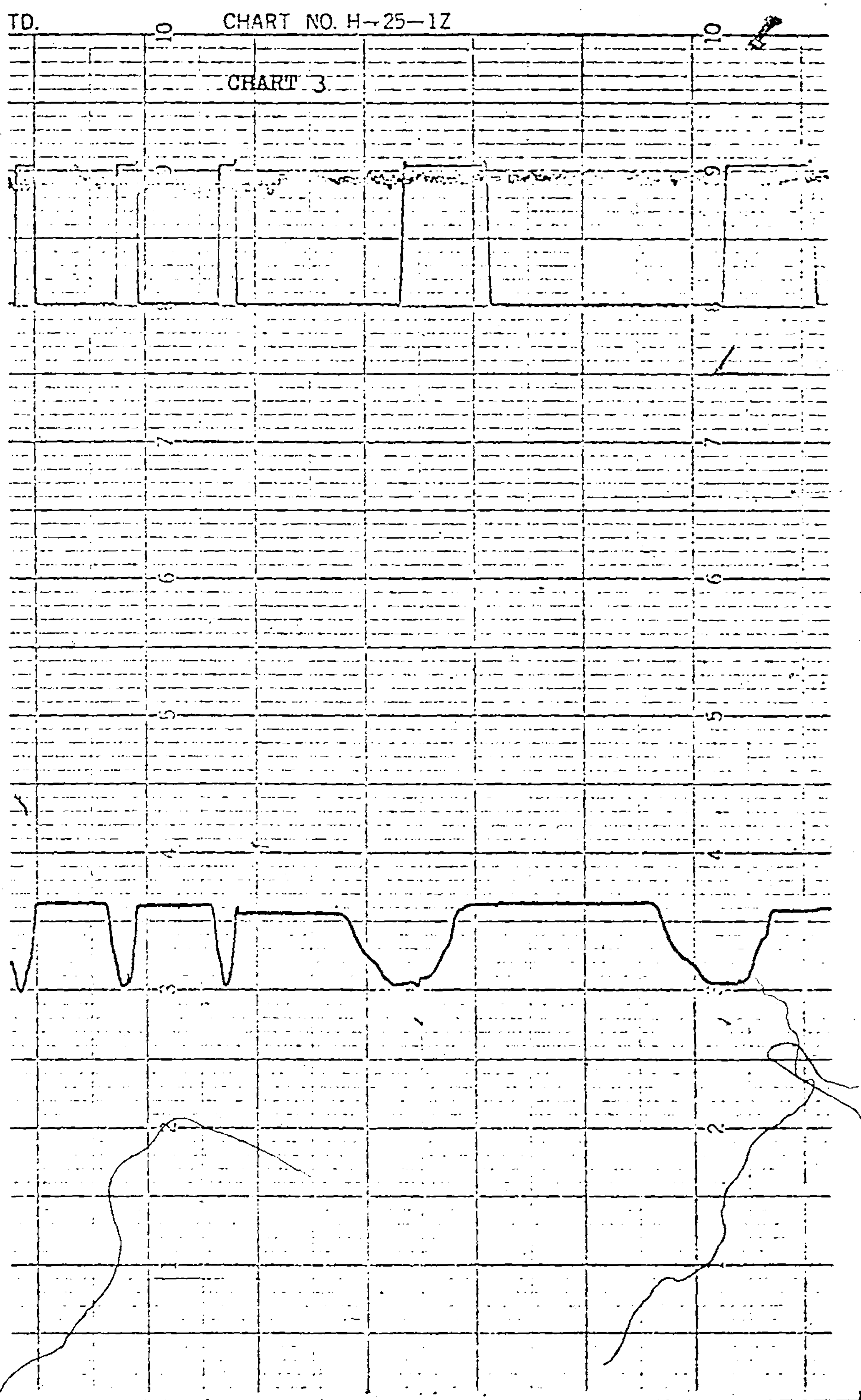
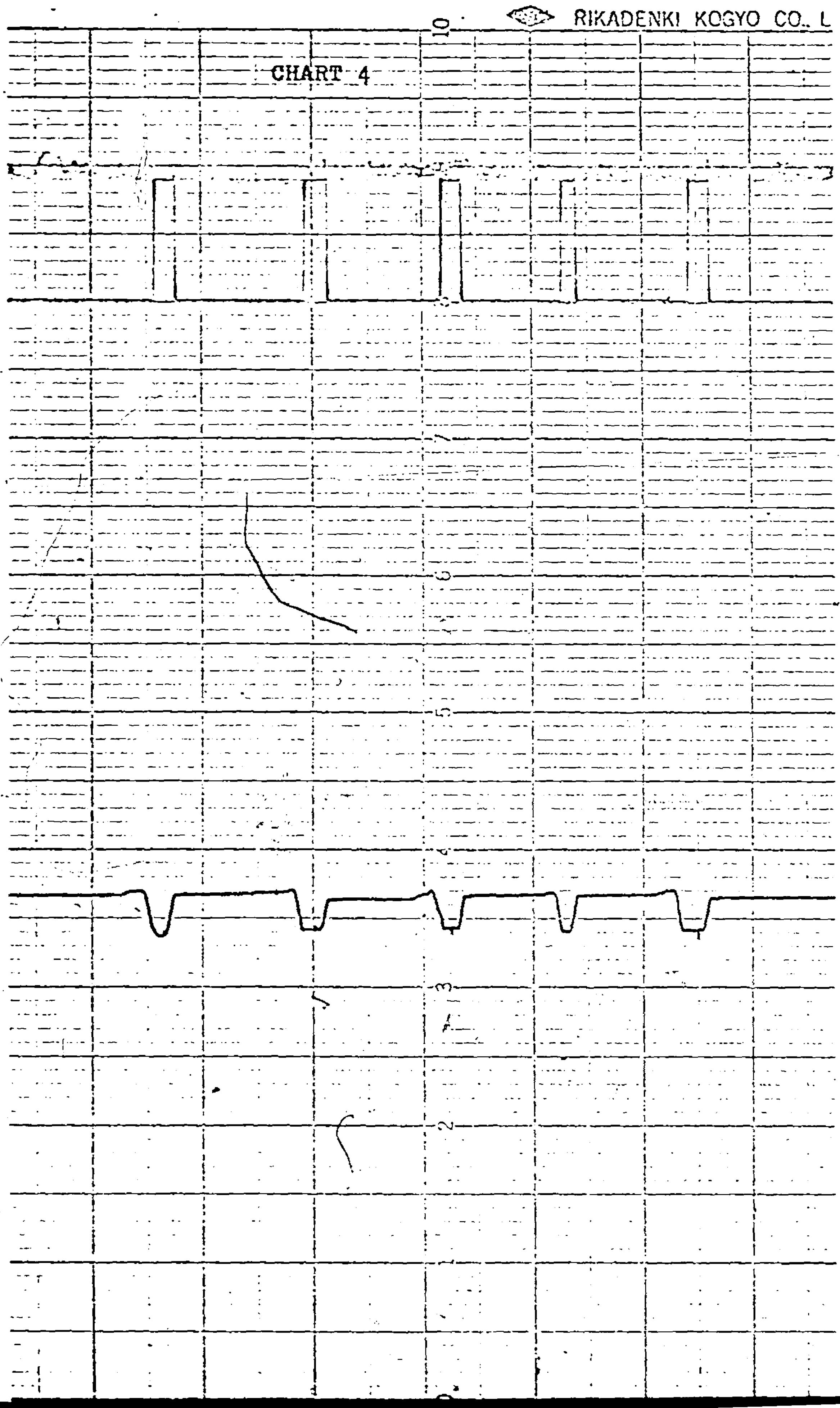
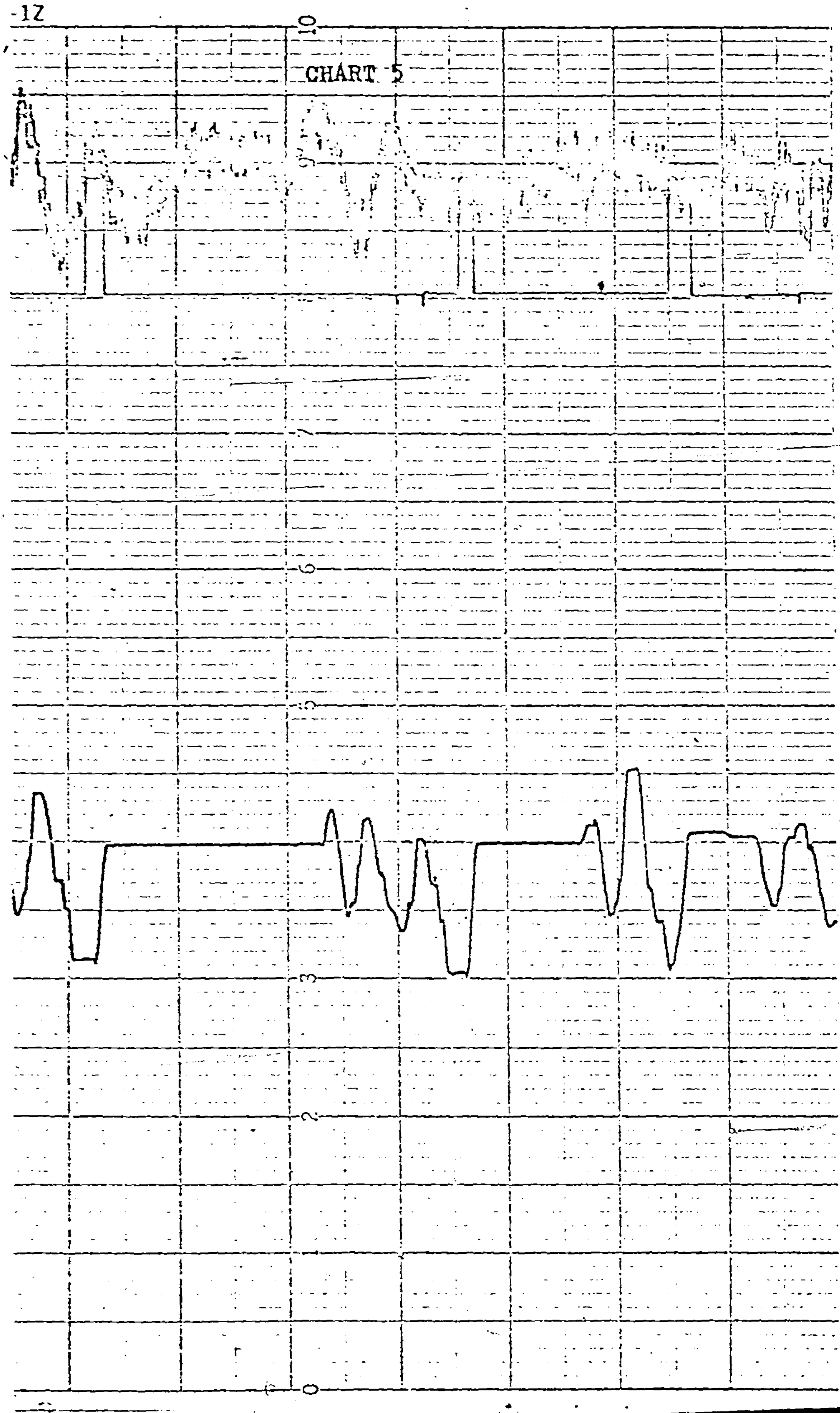


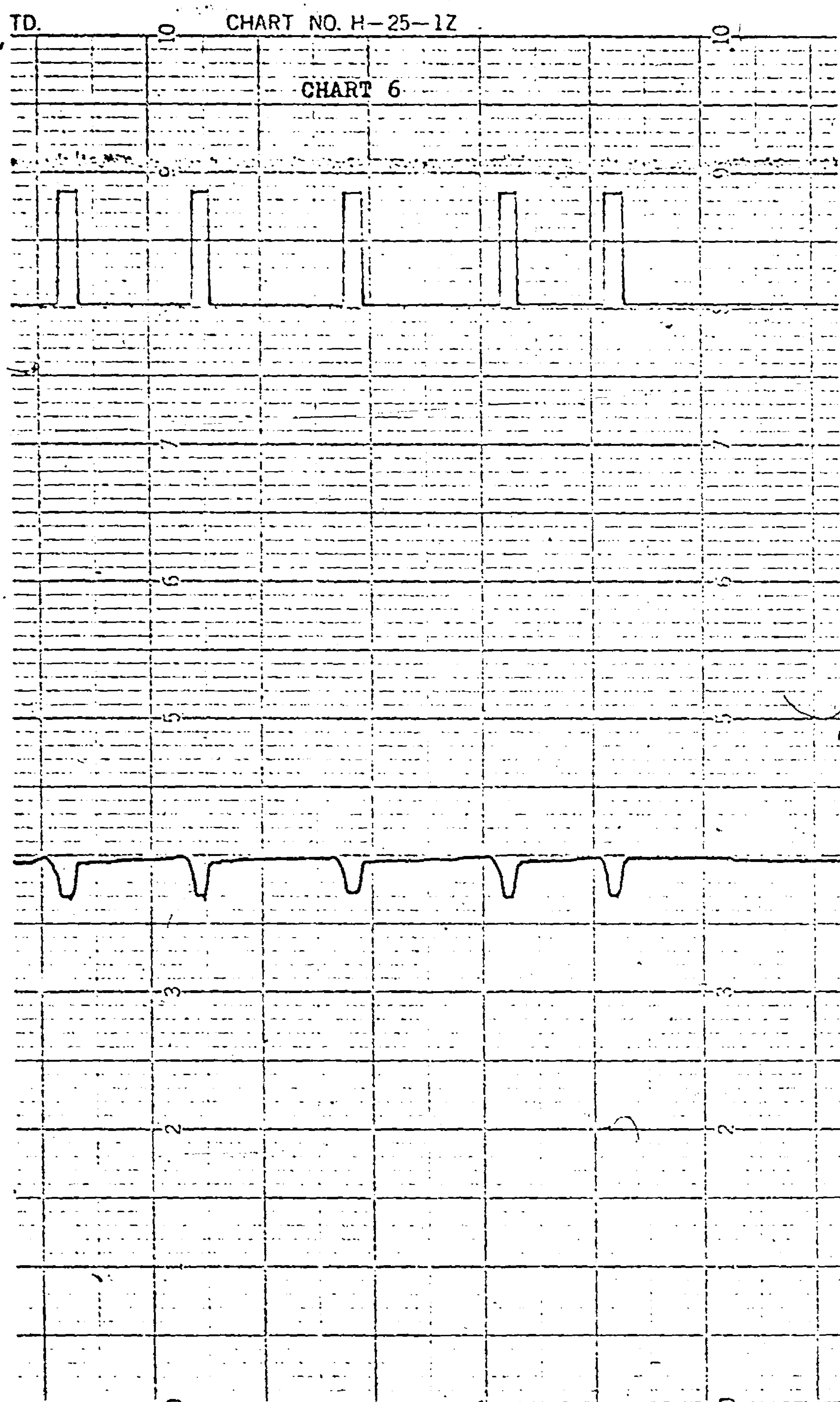
CHART 2

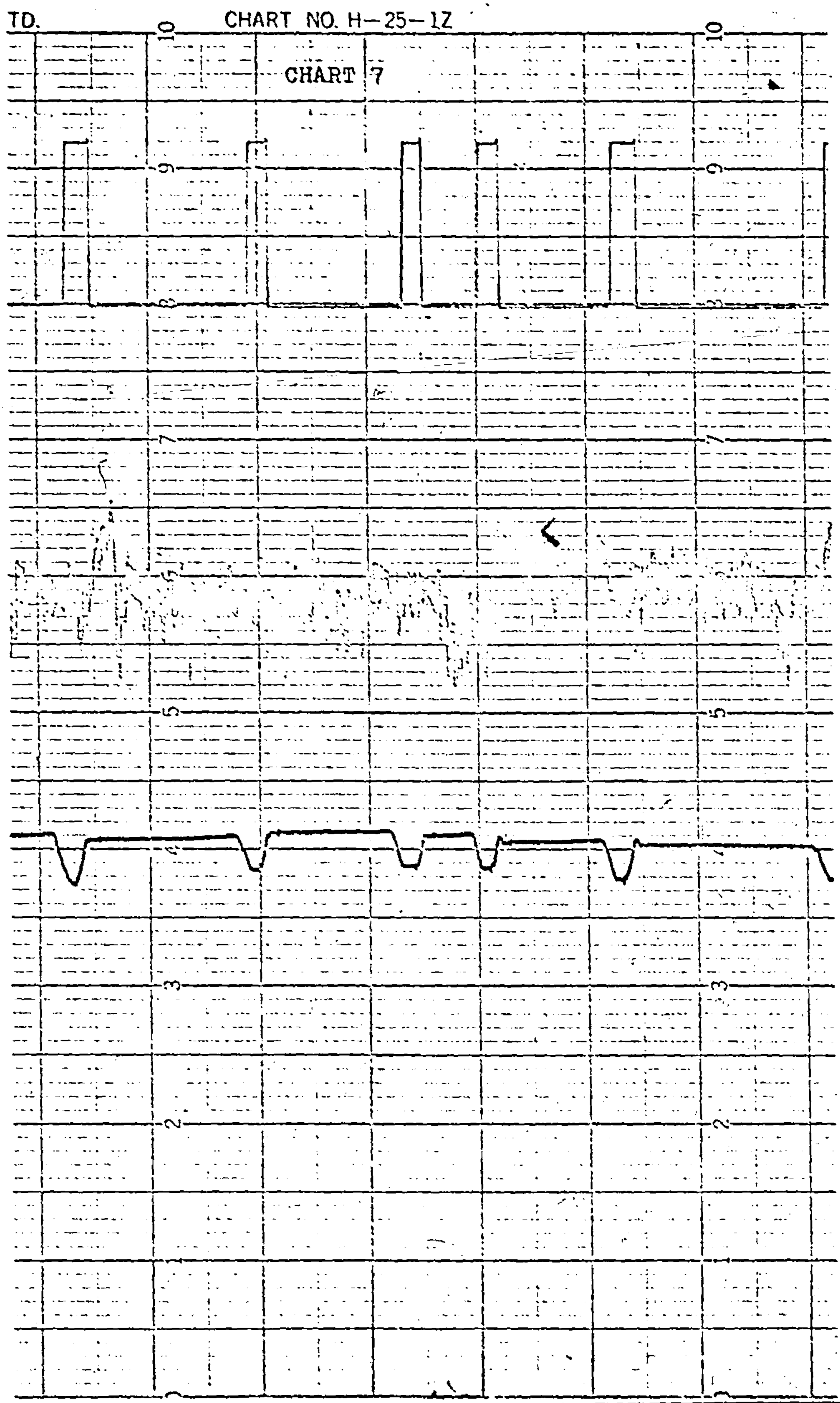

TD.
CHART NO. H-25-1Z
CHART 3

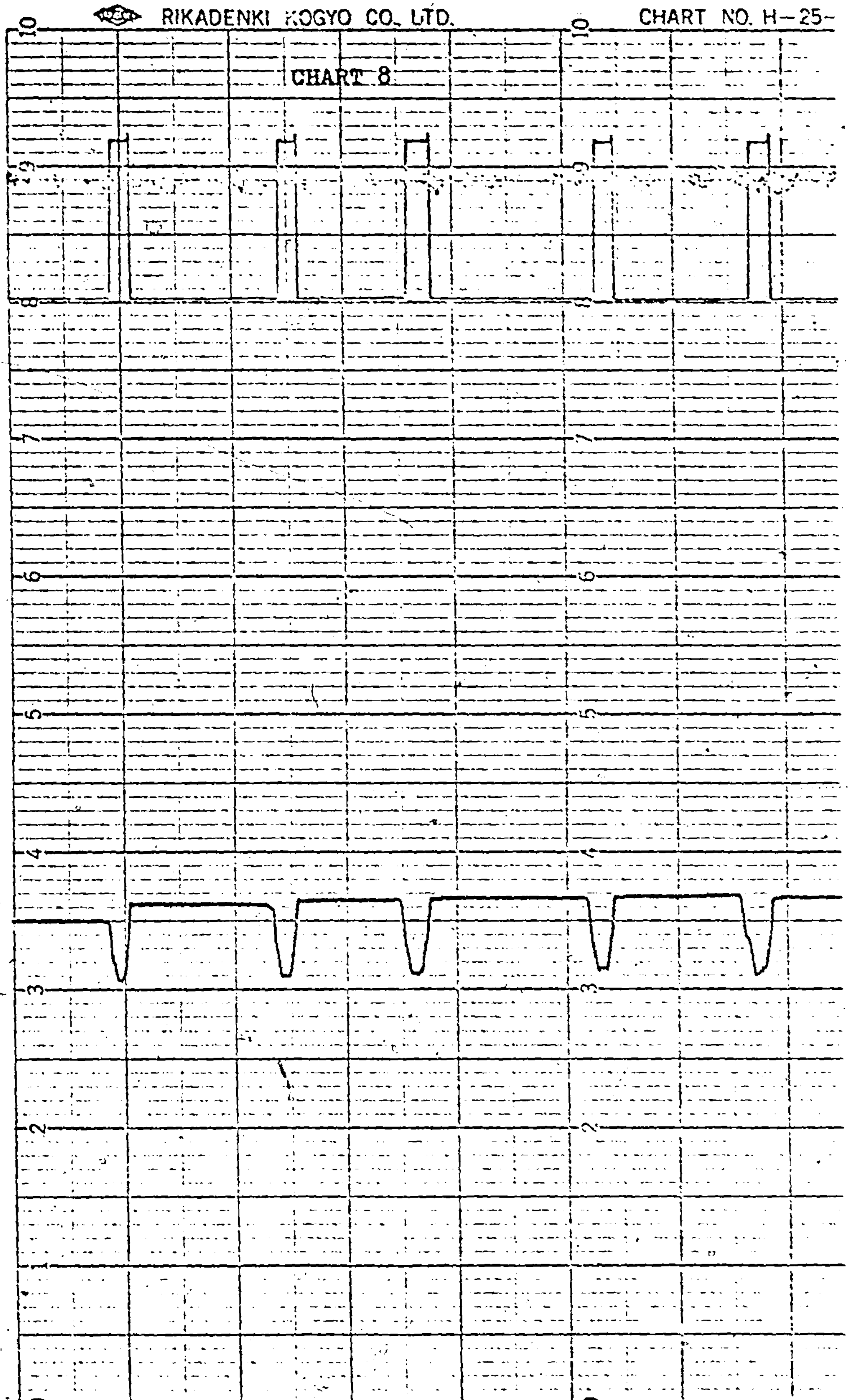

RIKADENKI KOGYO CO., L
CHART 4
10
9
8
7
6
5
4
3
2
1
0

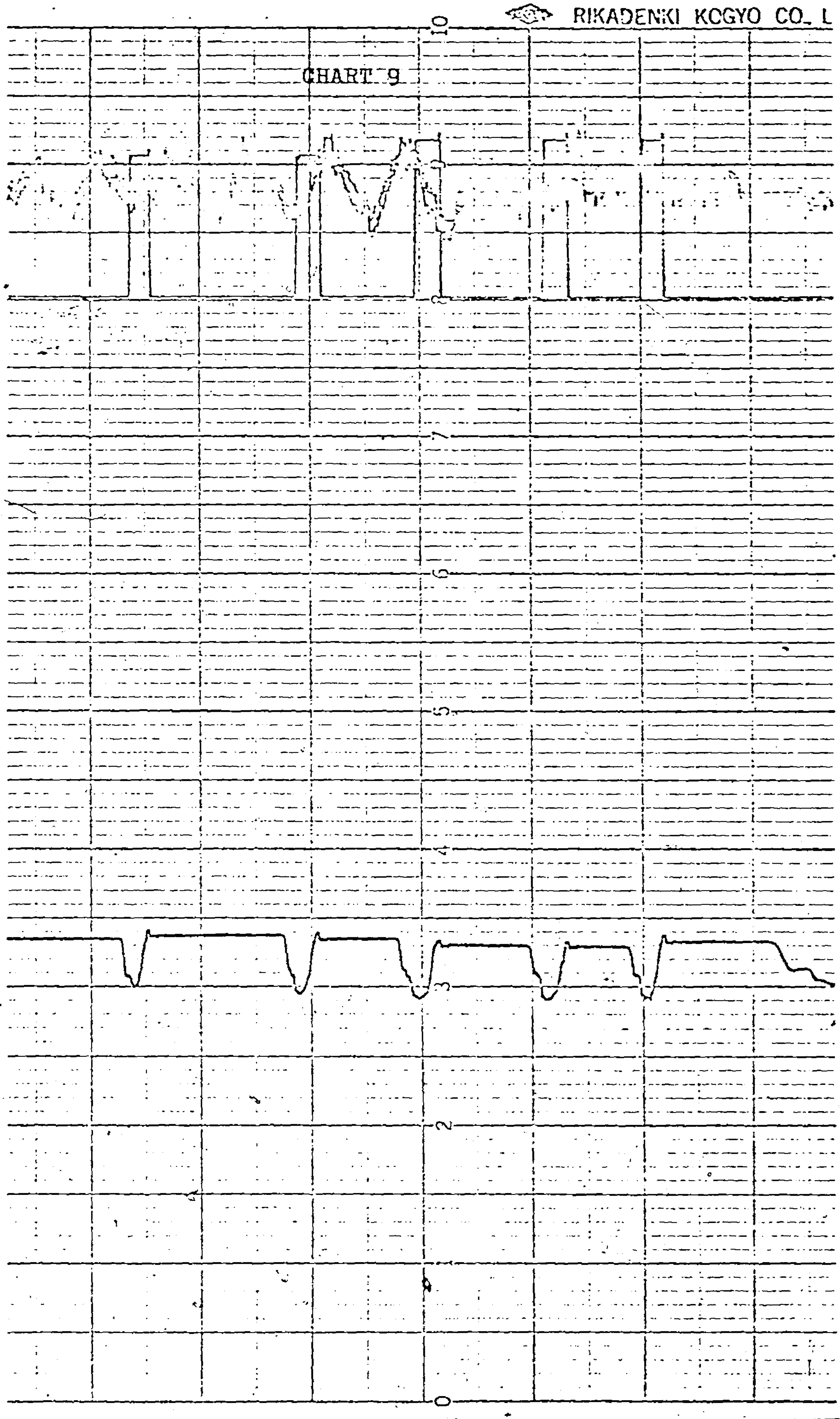


-12
10
CHART 5
9
5
3
2
0


TD.
CHART NO. H—25—1Z
CHART 6
10
9
7
6
5
3
2
0


TD.
CHART NO. H—25—1Z
CHART 7
10
9
8
7
6
5
4
3
2
1


RIKADENKI KOGYO CO. LTD.
CHART NO. H-25-
CHART 8
10
9
8
7
6
5
4
3
2
1
0


RIKADENKI KOGYO CO. L
CHART 9
10
7
6
5
4
3
2
0

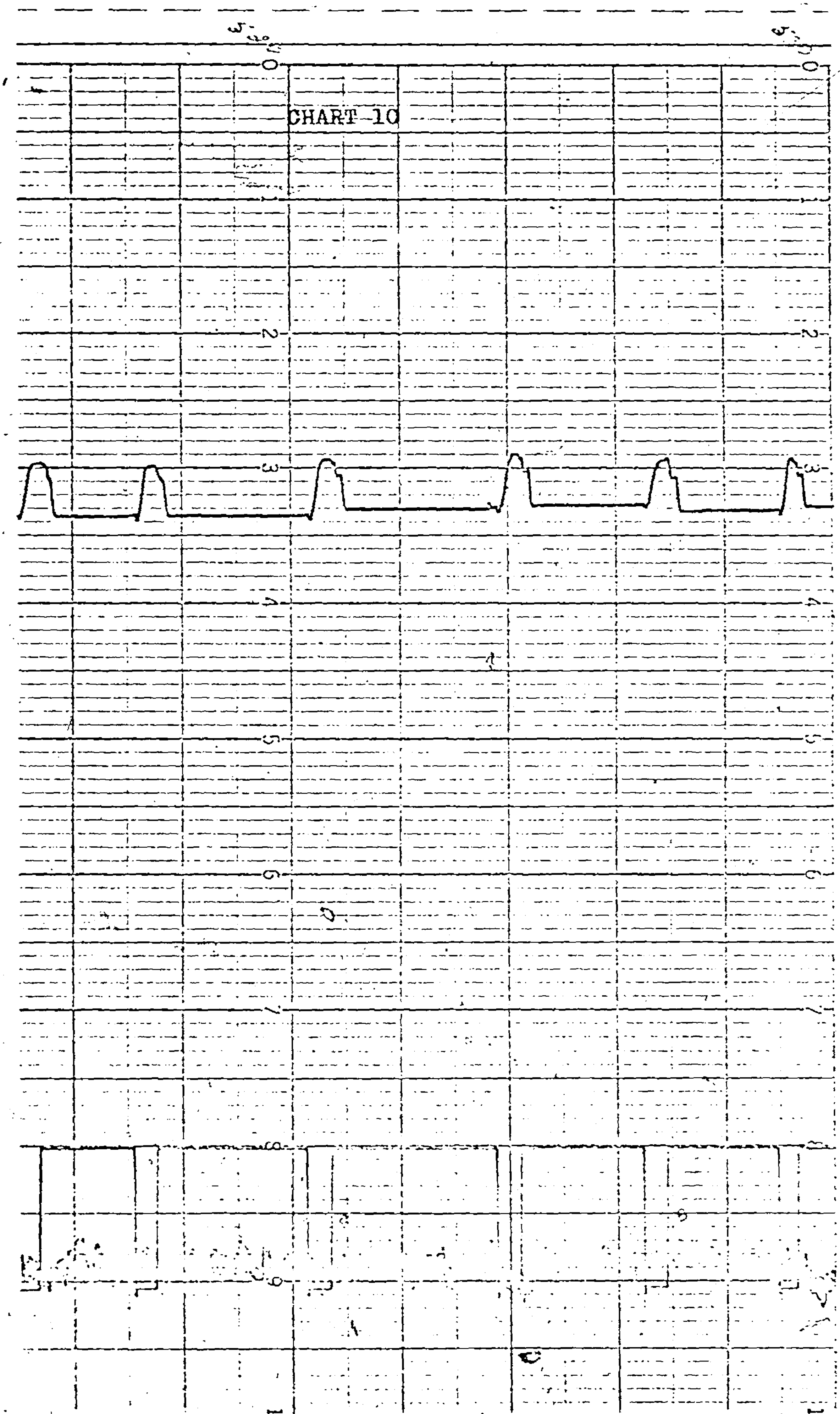
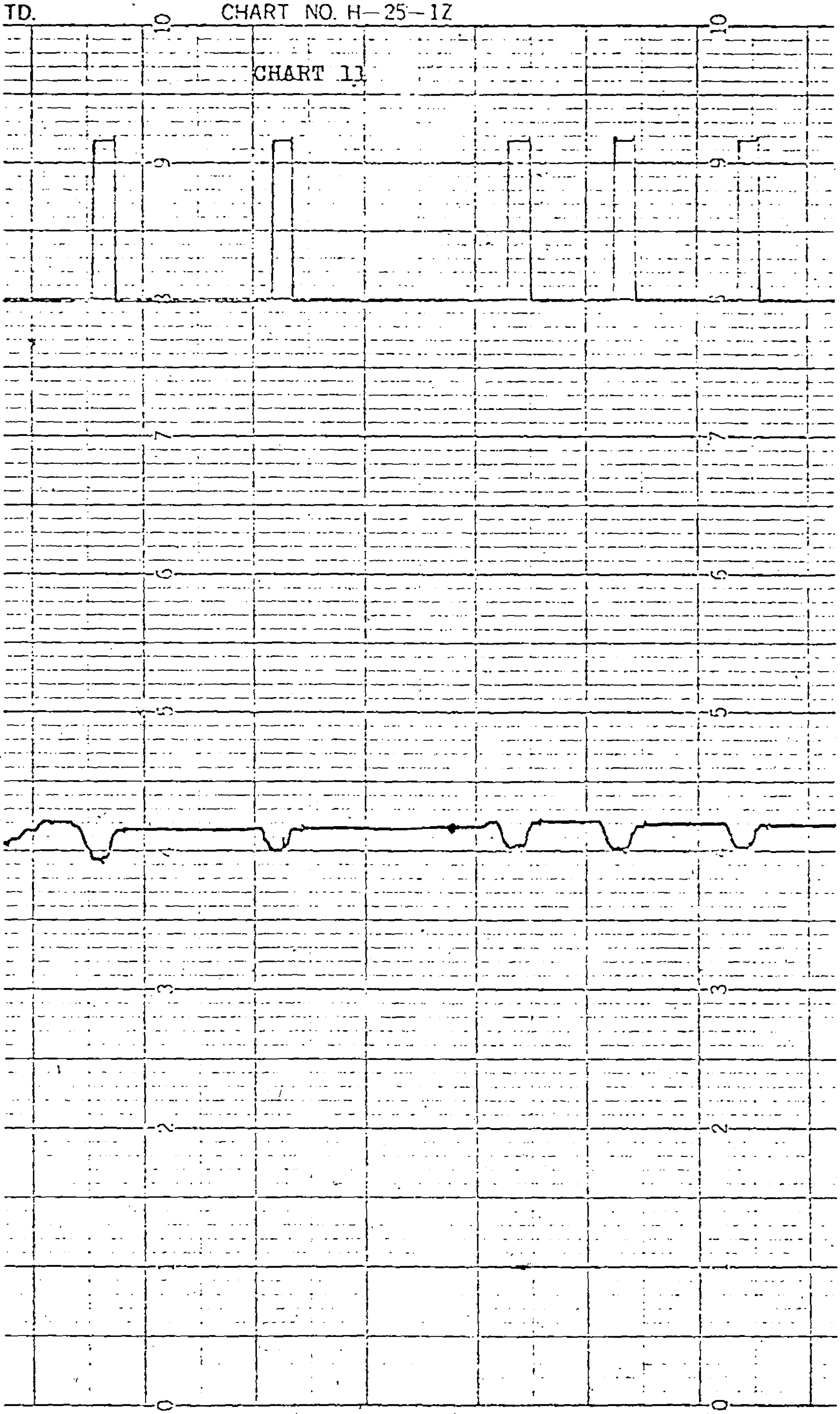


CHART 10

TD. CHART NO. H—25—1Z

CHART 11



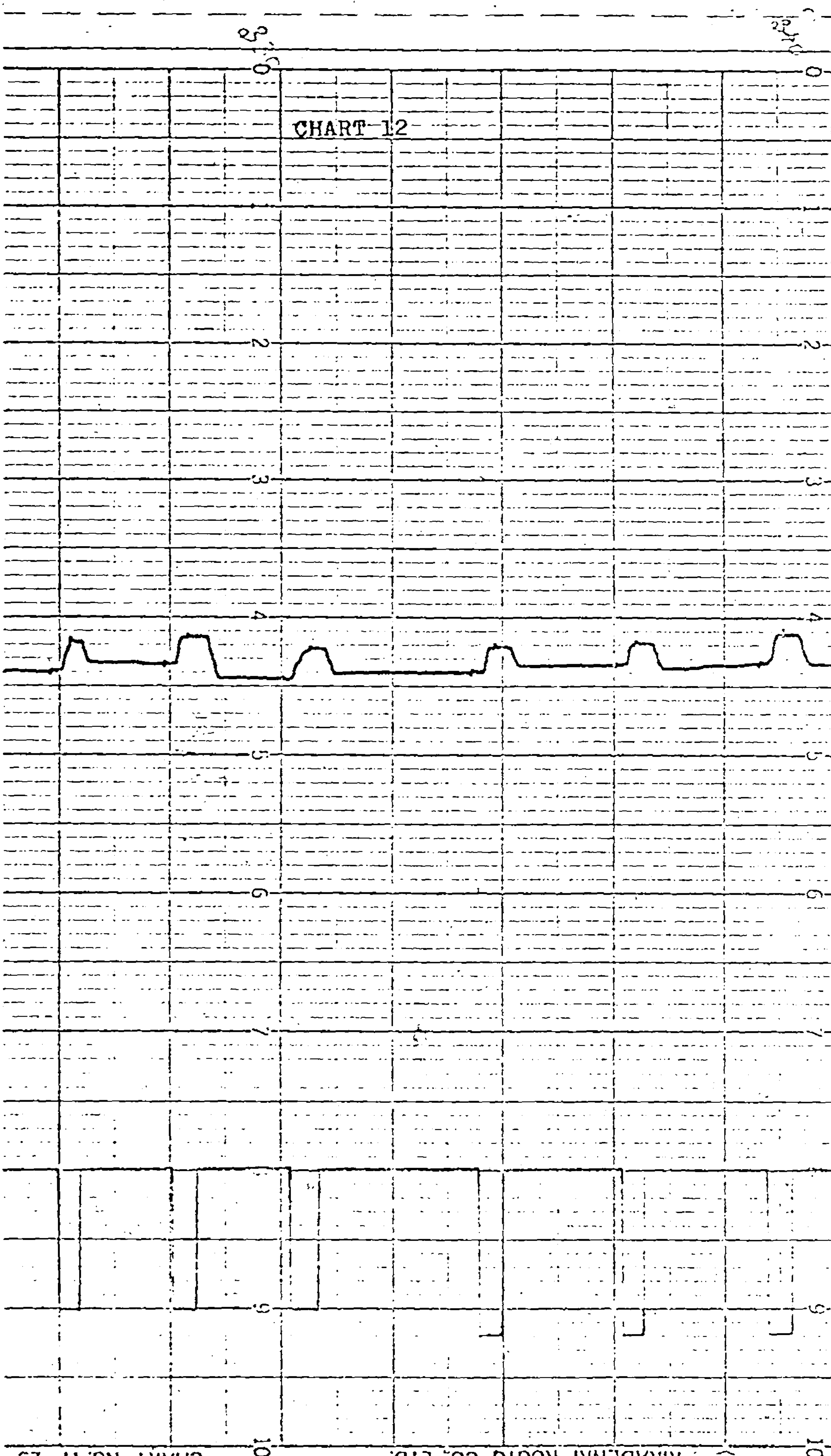
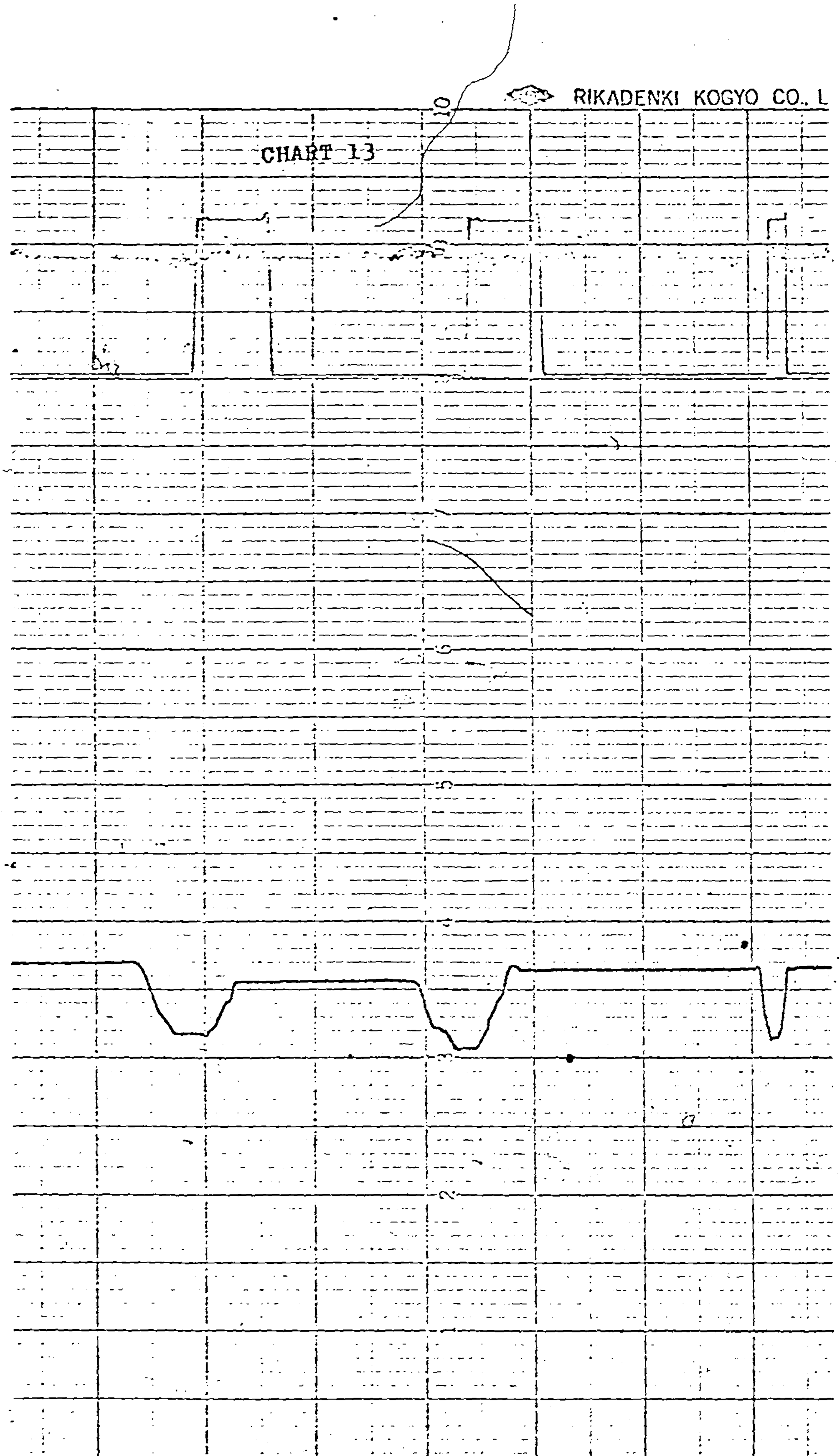
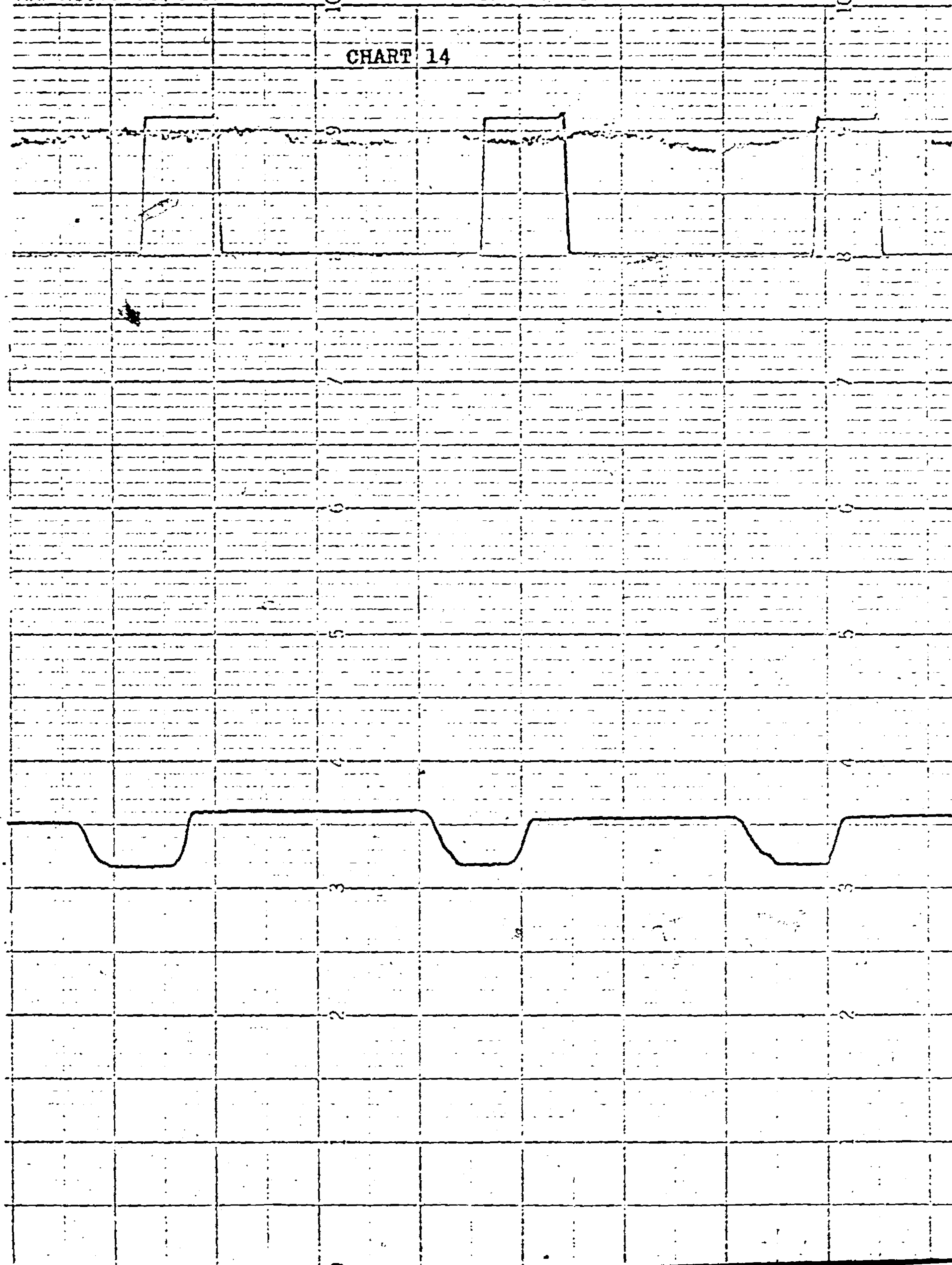


CHART 12


RIKADENKI KOGYO CO., L
CHART 13

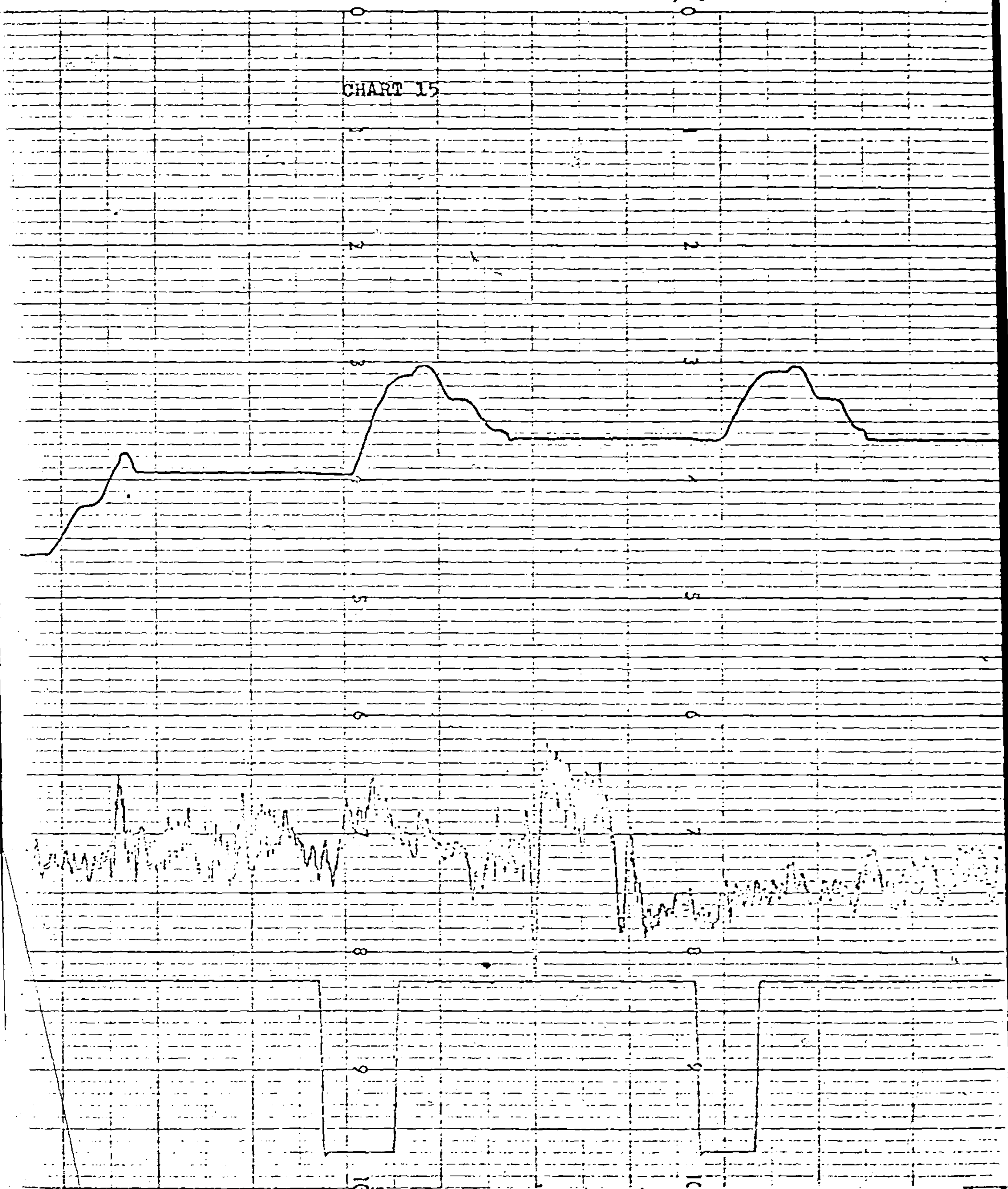
NKI KOGYO CO. LTD. CHART NO. H-25-1Z

CHART 14



790

CHART 15



APPENDIX F

SCHEMATIC DIAGRAMS

GUIDE TO SCHEMATIC DIAGRAMS

Figure 1 - Motor Control Circuit

SW1........................Main Switch

TDT........................Time Delay Tube

TDTC.......................Time Delay Tube Contact

F1, F2.....................Fuse

NL.........................Neon Lamp

D1, D2.....................Rectifier

D3, D4.....................Diodes

D5, D7.....................Diodes

D6.........................Triac

D9.........................SCR (Silicon Controlled Rectifier)

P, Q.......................Relay Contacts

A, B.......................Key Contacts

NOTE

——┼—— Break Contact - Normally closed, open when operated.

——x—— Make Contact - Normally open, closed when operated.

R1, R2 etc. Resistances

R1-1K, R2, R3, - 10K, 20K, R3-10K, C1, C2 etc. Capacitors

C1 -0, 1uf

FM........Field Motor

AM........Armature of Motor

Figure 2 Relay Control Circuit

TR1................ Transformer

L1, L2............. 6v Lamps

R4, R5............. 33K

R7, R8............. 33K

R6, R9............. 470

T1-T6.............. Transistors

P, Q............... Relays

Figure 3 Power Supply

TR2................ Transformers

D10-D13............ Rectifier Diodes

T7................. Transistor (2N3055)

C2................. 100uf

D14................ Zener Diode (10v)

R10................ 390

R11................ 1K

Figure 4 Recorder Pen Control Circuit

B1...............Battery (9v)

R12..............1.2K, R14 & R15.....10K

D15..............Zener Diode (3v)

R13..............Ten Turn Potentiometer (10K), R16...20K Potentiometer

Figure 5 Pulse Indicator Circuit

B2...............Battery (9v) C3..........5MF

R17..............1K R18..........10K Potentiometer

Figure 6 Turn Table Assembly

TT..............Turn Table

M...............Motor

B...............Base

PR..............Projector

Figure 7 Mechanical Direction Selector

SP..............Stationary Part

RP..............Rotating Part

R16.............Potentiometer R16 is connected to here (Not shown in fig.)

GC..............Gear Case

SWS.............Steering Wheel Shaft

Figure 8

1. Relay Control Circuit
2. Pen Control Circuit
3. Pulse Indicator Circuit
4. Motor Control Circuit
5. Multi - Pen Recorder
6. Turn Table, Projector, Motor etc.
7. Tape Recorder
8. Precision Sound Level Circuit
9. Mechanical Direction Selector

MOTOR CONTROL CIRCUIT

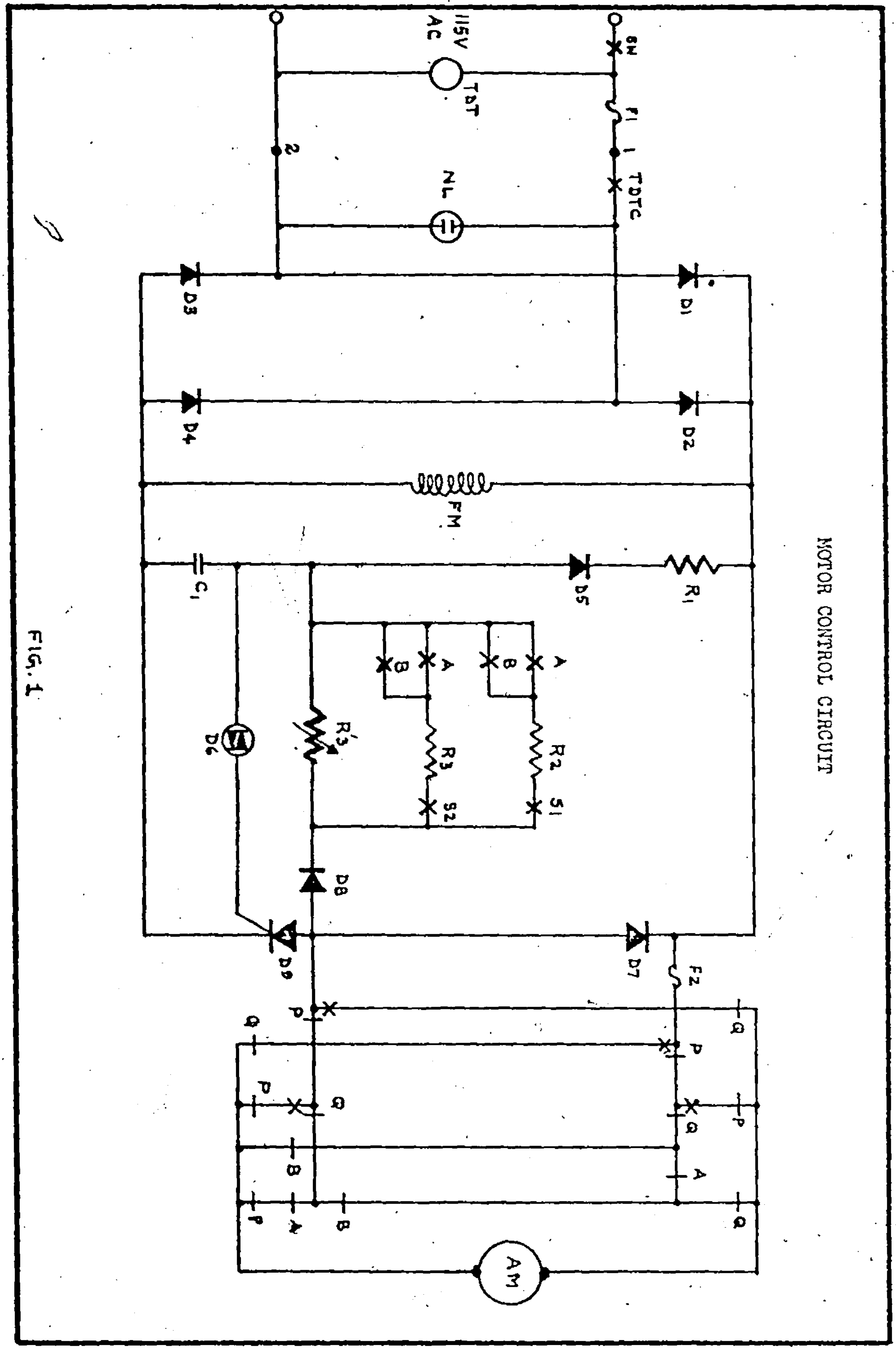


FIG. 1

RELAY CONTROL CIRCUIT

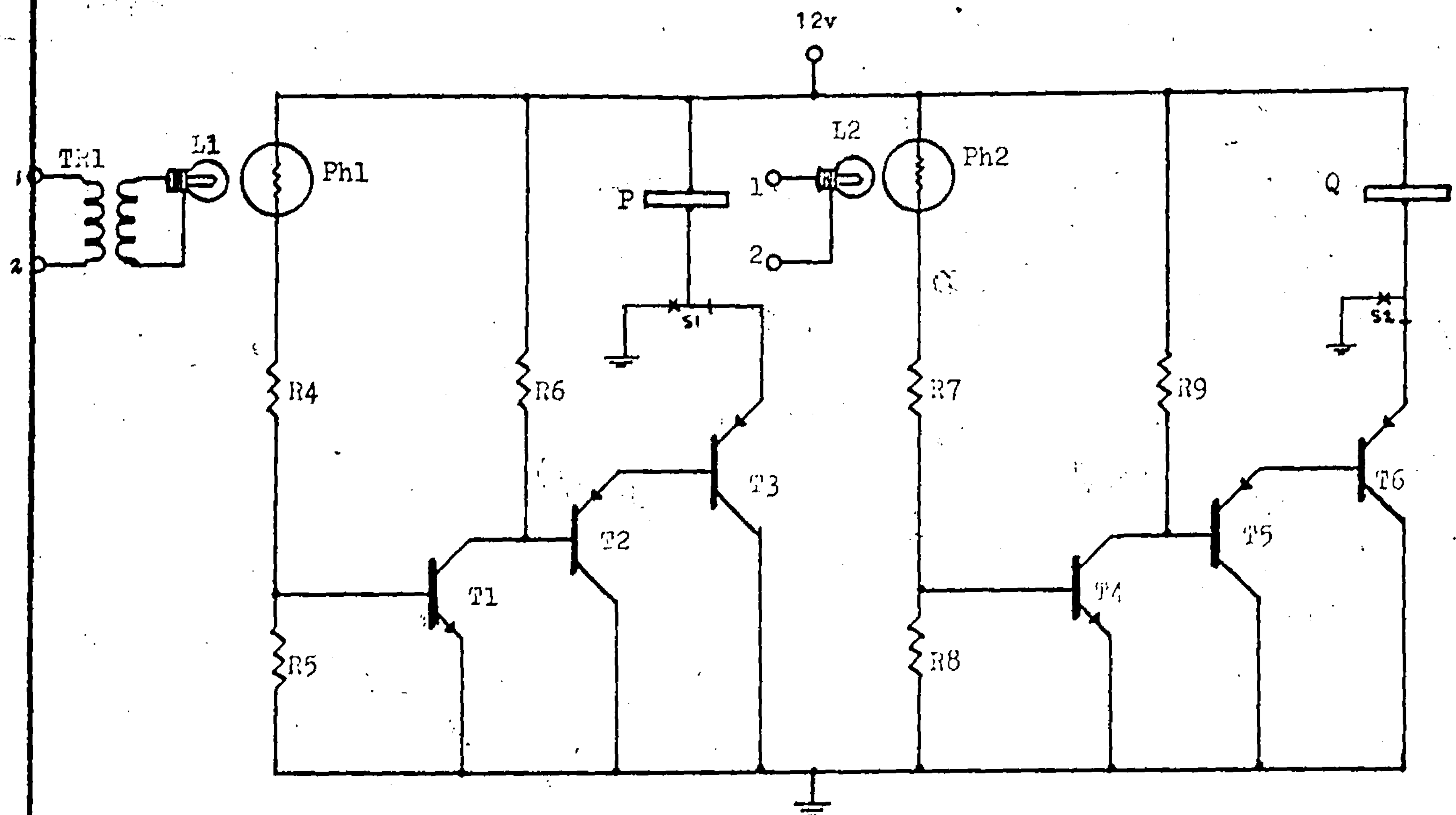


Fig 2

POWER SUPPLY

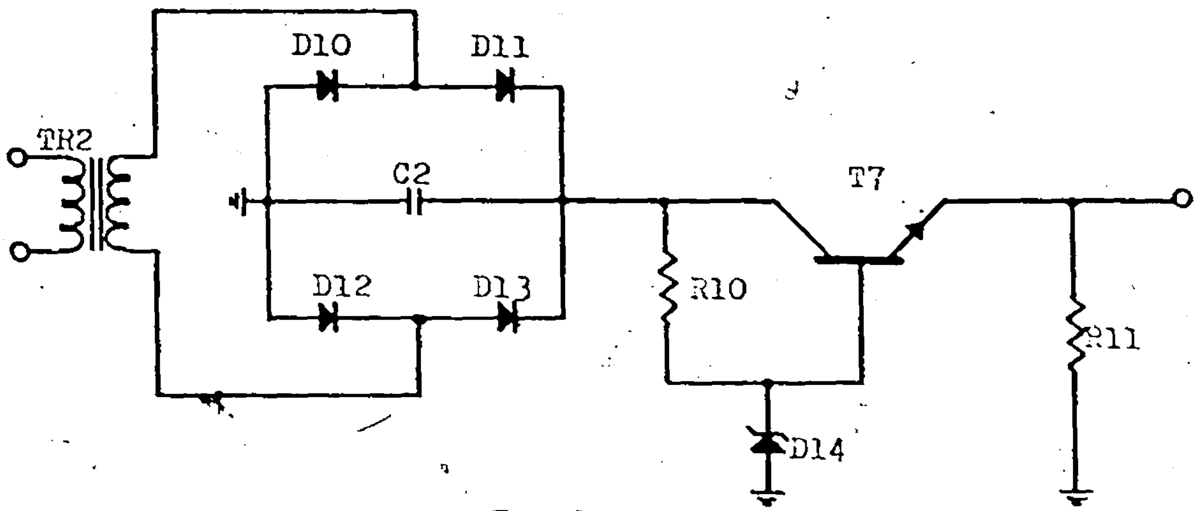


Fig 3

RECORDER PEN CONTROL

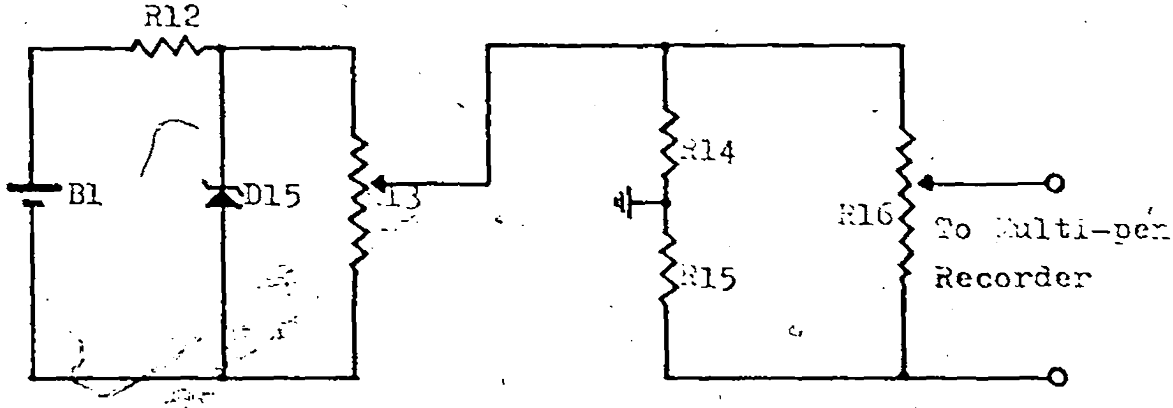
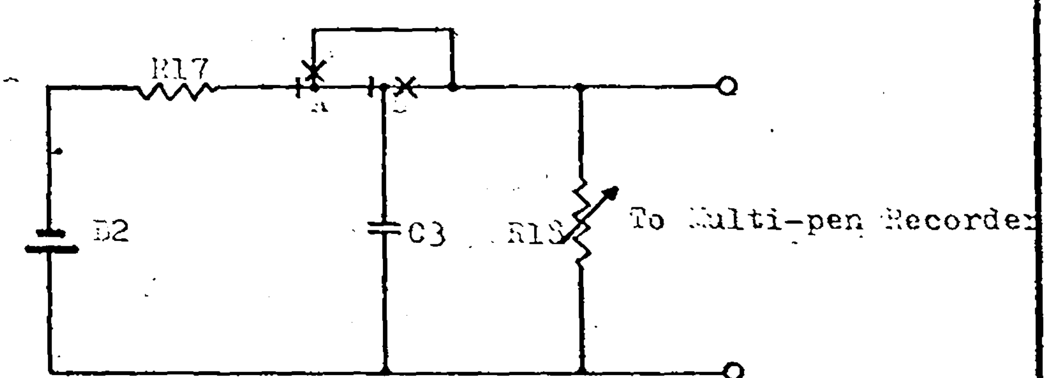
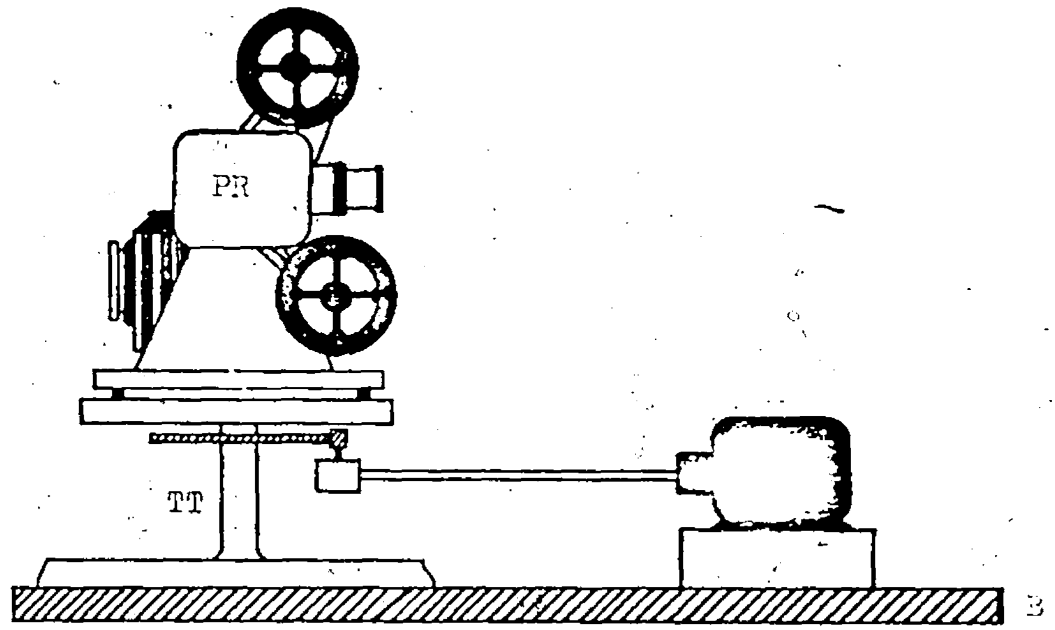


Fig 4

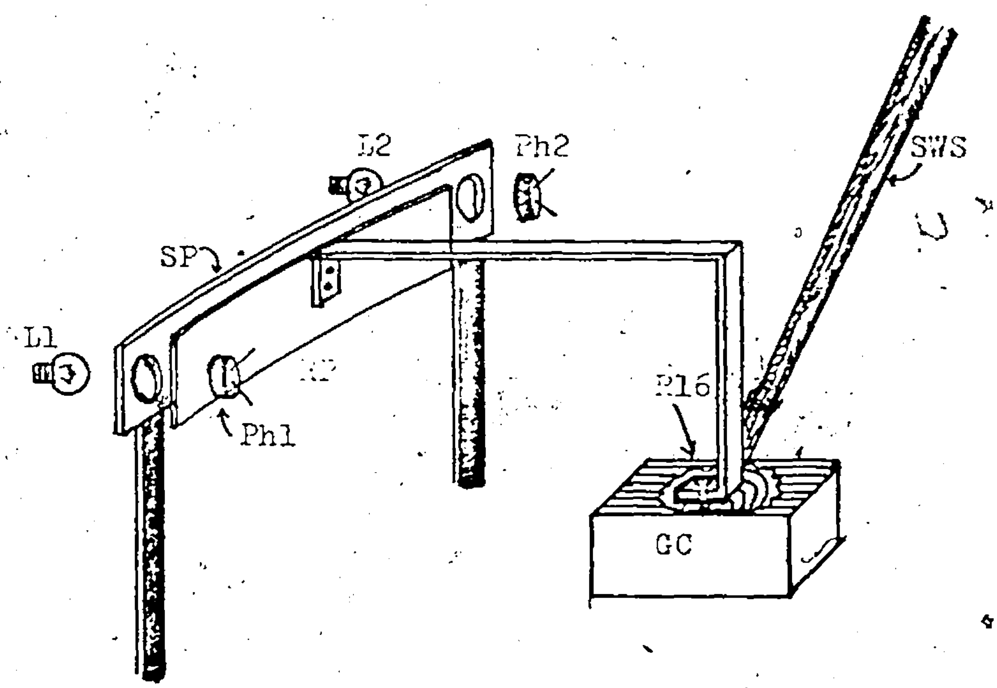


PULSE INDICATOR CIRCUIT
Fig 5



TURNTABLE ASSEMBLY

Fig.6



MECHANICAL DIRECTION SELECTOR

Fig.7

GENERAL VIEW OF EXPERIMENTAL SET UP.

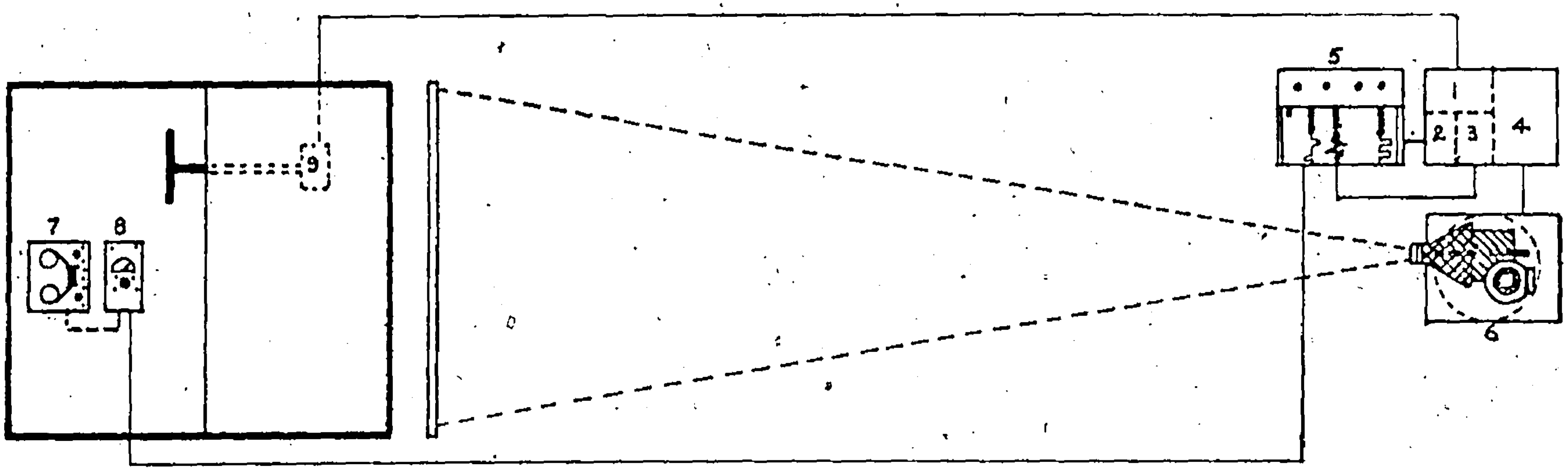


FIG 8

APPENDIX G

COMPUTER PROGRAM AND PRINTOUTS

```
      DIMENSION X(3000)
      DIMENSION HEAD(6),LEVEL(6),ISTEP(6),KOUNT(6),LASTS(6)
      DIMENSION SUMSQ(63),NDF(63),SMEAN(63)
      DIMENSION FMT(15)
    1 FORMAT(A4,A2,I2,A4,3X,11(A1,I4)/(A1,I4,A1,I4,A1,I4,A1,I4,A1,I4)
    2 FORMAT(20H1ANALYSIS OF VARIANCE.....A4,A2//)
    3 FORMAT(10H0LEVELS OF FACTORS/(3X,A1,7X,I4))
    4 FORMAT(1H0//11H GRAND MEANF20.5////)
    5 FORMAT(10H0SOURCE OF13X,7HSUMS OF10X,10HDEGREES OF9X,4HMEAN/10H
     1VARIATION13X,7HSQUARES11X,7HFREEDOM10X,7HSQUARES/)
    6 FORMAT(1H 15A1,F20.5,10X,I6,F20.5)
    7 FORMAT(6H TOTAL10X,F20.5,10X,I6)
    8 FORMAT(9F6.3)
  100 READ (5,1) PR,PR1,K,BLANK,(HEAD(I),LEVEL(I),I=1,K)
      WRITE (6,2) PR,PR1
      WRITE (6,3) (HEAD(I),LEVEL(I),I=1,K)
      N=LEVEL(1)
      DO 102 I=2,K
  102 N=N*LEVEL(I)
      READ (5,8) (X(I),I=1,N)
      WRITE (6,8) (X(I),I=1,N)
      CALL AVDAT (K,LEVEL,N,X,L,ISTEP,KOUNT)
      CALL AVCAL (K,LEVEL,X,L,ISTEP,LASTS)
      CALL MEANQ (K,LEVEL,X,GMEAN,SUMSQ,NDF,SMEAN,ISTEP,KOUNT,LASTS)
      WRITE (6,4) GMEAN
      WRITE (6,5)
      LL=(2**K)-1
      ISTEP(1)=1
      DO 105 I=2,K
  105 ISTEP(I)=0
      DO 110 I=1,15
  110 FMT(I)=BLANK
      NN=0
      SUM=0.0
  120 NN=NN+1
      L=0
      DO 140 I=1,K
      FMT(I)=BLANK
      IF(ISTEP(I)) 130, 140, 130
  130 L=L+1
      FMT(L)=HEAD(I)
  140 CONTINUE
      WRITE (6,6) (FMT(I),I=1,15),SUMSQ(NN),NDF(NN),SMEAN(NN)
      SUM=SUM+SUMSQ(NN)
      IF(NN-LL) 145, 170, 170
  145 DO 160 I=1,K
      IF(ISTEP(I)) 147, 150, 147
  147 ISTEP(I)=0
```

```
      GO TO 160
  150 ISTEP(I)=1
      GO TO 120
  160 CONTINUE
  170 N=N-1
      WRITE (6,7) SUM,N
      GO TO 100
      END
```

ANALYSIS OF VARIANCE.....BECK1

LEVELS OF FACTORS

S	3
N	3
R	3

1.024	1.104	0.744	1.064	1.020	1.100	1.060	0.894	1.064
0.984	1.104	0.904	1.060	0.8[illegible]	0.984	1.016	0.946	0.826
0.823	1.024	0.756	1.024	0.816	0.956	0.984	0.866	1.040

GRAND MEAN 0.96567

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.02473	2	0.01236
N	0.01091	2	0.00545
SN	0.14365	4	0.03591
R	0.03429	2	0.01715
SR	0.00804	4	0.00201
NR	0.02690	4	0.00673
SNR	0.04821	8	0.00603
TOTAL	0.29674	26	

ANALYSIS OF VAPIANCE.....BECK2

LEVELS OF FACTORS

S	3
N	3
R	3

0.663	1.184	0.886	0.663	1.006	0.864	1.010	1.024	0.894
0.944	1.024	0.904	0.928	0.986	0.944	1.126	1.104	1.064
1.024	1.024	0.784	0.946	0.984	0.976	0.996	1.020	0.944

GRAND MEAN 0.95948

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.08670	2	0.04335
N	0.04909	2	0.02455
SN	0.04790	4	0.01198
R	0.03985	2	0.01993
SR	0.07277	4	0.01819
NR	0.01931	4	0.00483
SNR	0.05404	8	0.00676
TOTAL	0.36967	26	

ANALYSIS OF VARIANCE.....CIRJHI

LEVELS OF FACTORS

S	3
N	3
R	3

1.304	0.690	0.696	0.824	0.901	0.904	0.944	0.864	1.104
1.024	0.694	0.676	0.904	0.820	0.824	1.144	0.784	0.824
1.040	1.020	0.944	0.744	0.824	0.864	1.064	0.724	0.824

GRAND MEAN 0.88752

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.17488	2	0.08744
N	0.02608	2	0.01304
SN	0.15803	4	0.03951
R	0.01723	2	0.00861
SR	0.03431	4	0.00858
NR	0.06840	4	0.01710
SNR	0.15060	8	0.01882
TOTAL	0.62953	26	

ANALYSIS OF VARIANCE.....CIPJU2

LEVELS OF FACTORS

S	3
N	3
R	3

1.140	0.904	0.864	0.880	0.956	0.816	0.904	1.004	1.160
1.084	0.864	1.024	0.864	0.836	0.836	0.876	0.936	1.068
1.128	1.184	0.594	0.904	0.766	0.984	0.836	1.024	1.198

GRAND MEAN 0.96015

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01540	2	0.00770
N	0.13641	2	0.06820
SN	0.15958	4	0.03989
R	0.02350	2	0.01175
SR	0.01409	4	0.00352
NR	0.01554	4	0.00389
SNR	0.05866	8	0.00733
TOTAL	0.42317	26	

ANALYSIS OF VARIANCE.....FOWIN1

LEVELS OF FACTORS

S	3
N	3
R	3

1.080	1.064	1.184	0.824	0.920	1.060	1.144	1.040	1.184
0.836	1.024	1.060	1.264	1.304	1.304	1.304	1.264	1.264
1.024	0.684	0.676	0.904	0.820	0.824	1.144	0.784	0.824

GRAND MEAN 1.03000

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.02351	2	0.01176
N	0.09745	2	0.04872
SN	0.03271	4	0.00818
R	0.48917	2	0.24459
SR	0.15083	4	0.03771
NR	0.18481	4	0.04620
SNR	0.03311	8	0.00414
TOTAL	1.01157	26	

ANALYSIS OF VARIANCE.....EDWIN2

LEVELS OF FACTORS

S	3
N	3
R	3

1.184	1.124	1.044	1.056	0.988	0.968	0.866	1.024	1.124
0.904	0.836	0.966	0.966	1.006	0.706	0.926	1.026	0.926
1.124	1.024	0.988	1.060	0.966	0.904	0.926	1.144	1.144

GRAND MEAN 0.99704

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.00777	2	0.00389
N	0.02124	2	0.01062
SN	0.09955	4	0.02489
R	0.08487	2	0.04243
SR	0.00720	4	0.00180
NR	0.02647	4	0.00662
SNR	0.05553	8	0.00695
TOTAL	0.30268	26	

ANALYSIS OF VARIANCE.....REMO1

LEVELS OF FACTORS

S	3
N	3
R	3

0.794 1.144 1.024 0.824 0.666 0.664 0.904 0.944 1.024
0.772 0.864 1.224 0.824 0.686 0.996 1.064 1.144 1.184
0.746 0.864 1.224 0.744 0.356 1.624 0.986 0.956 0.866

GRAND MEAN 0.92600

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.14639	2	0.07319
N	0.19383	2	0.09692
SN	0.12282	4	0.03071
R	0.03457	2	0.01729
SR	0.05339	4	0.01335
NR	0.07624	4	0.01906
SNR	0.11023	8	0.01379
TOTAL	0.73753	26	

ANALYSIS OF VARIANCE.....RCUO2

LEVELS OF FACTORS

S	3
N	3
R	3

0.784	0.724	0.776	0.664	0.664	1.034	0.784	1.084	1.024
0.772	0.664	0.756	0.804	0.664	0.966	0.746	0.796	1.024
0.746	0.984	1.046	0.744	0.656	1.064	0.656	1.024	1.204

GRAND MEAN 0.85237

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.31293	2	0.15646
N	0.11500	2	0.05750
SN	0.15187	4	0.03797
R	0.06921	2	0.03461
SR	0.08428	4	0.02107
NR	0.03812	4	0.00953
SNR	0.05064	8	0.00633
TOTAL	0.82205	26	

ANALYSIS OF VARIANCE.....WAYNE1

LEVELS OF FACTORS

S	3
N	3
R	3

0.882	0.916	1.046	1.064	0.976	0.904	1.228	1.000	1.064
0.904	0.834	0.966	0.966	1.006	0.706	0.926	1.026	0.926
0.886	0.904	0.806	1.021	1.024	0.956	1.046	1.064	0.816

GRAND MEAN 0.95418

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.02662	2	0.01331
N	0.04016	2	0.02008
SN	0.04501	4	0.01125
R	0.04151	2	0.02076
SR	0.02914	4	0.00729
NR	0.03168	4	0.00792
SNR	0.06159	8	0.00769
TOTAL	0.27567	26	

ANALYSIS OF VARIANCE.....WAYNE2

LEVELS OF FACTORS

S	3
N	3
R	3

0.846 0.672 0.716 0.856 0.756 0.984 1.306 0.906 0.846
0.984 0.876 0.506 0.946 0.766 0.872 1.146 1.076 0.836
0.944 0.784 0.696 0.766 1.024 0.796 1.064 0.966 1.024

GRAND MEAN 0.90555

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.08869	2	0.04434
N	0.18379	2	0.09190
SN	0.07237	4	0.01809
R	0.02289	2	0.01145
SR	0.04036	4	0.01009
NP	0.04270	4	0.01068
SNR	0.12632	8	0.01579
TOTAL	0.57711	26	

ANALYSIS OF VARIANCE.....PRELY1

LEVELS OF FACTORS

S	3
N	3
R	3

1.224	1.222	1.144	0.704	0.826	0.706	0.636	1.064	0.824
0.744	1.264	0.984	0.664	0.718	0.916	0.716	0.756	0.886
1.264	1.184	1.264	0.744	0.710	0.976	1.064	0.886	0.736

GRAND MEAN 0.91578

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.04352	2	0.02176
N	0.72932	2	0.36466
SN	0.03159	4	0.00790
R	0.06674	2	0.03337
SR	0.11811	4	0.02953
NR	0.05170	4	0.01292
SNR	0.17279	8	0.02160
TOTAL	1.21377	26	

ANALYSIS OF VARIANCE.....PRELY2

LEVELS OF FACTORS

S	3
N	3
R	3

0.944	1.024	1.184	0.984	0.784	0.682	0.984	0.784	0.266
1.104	1.064	1.344	0.664	0.784	0.986	0.864	0.784	0.726
1.104	0.744	1.104	0.864	0.784	0.784	1.264	0.664	0.916

GRAND MEAN 0.91792

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.12098	2	0.06049
N	0.32181	2	0.16091
SN	0.12651	4	0.03163
R	0.00058	2	0.00029
SR	0.11827	4	0.02957
NR	0.09012	4	0.02253
SNR	0.11216	8	0.01402
TOTAL	0.89044	26	

ANALYSIS OF VARIANCE......GASPR1

LEVELS OF FACTORS

S	3
N	3
R	3

0.924	0.932	1.104	0.940	0.894	0.734	0.530	0.664	0.424
0.903	0.921	0.944	0.874	0.864	0.682	0.510	0.612	0.664
0.991	0.874	1.186	0.850	0.872	0.651	0.540	0.601	0.632

GRAND MEAN 0.73767

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.00416	2	0.00208
N	0.70145	2	0.35073
SN	0.12891	4	0.03223
R	0.00304	2	0.00152
SR	0.00954	4	0.00239
NR	0.02264	4	0.00566
SNR	0.04884	8	0.00611
TOTAL	0.91860	26	

ANALYSIS OF VARIANCE.....GASP22

LEVELS OF FACTORS

S	3
N	3
R	3

1.100	1.220	1.180	0.784	0.816	0.704	0.654	0.424	0.664
0.920	0.928	1.020	0.820	0.320	0.820	0.642	0.435	0.676
0.904	0.874	1.120	0.760	0.810	0.924	0.581	0.543	0.624

GRAND MEAN 0.80693

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.04228	2	0.02114
N	0.89023	2	0.44511
SN	0.05043	4	0.01261
R	0.01350	2	0.00675
SR	0.01989	4	0.00497
NR	0.07828	4	0.01957
SNR	0.03461	8	0.00433
TOTAL	1.12920	26	

ANALYSIS OF VARIANCE.......MSELY1

LEVELS OF FACTORS

S	3
N	3
R	3

0.696	1.270	1.180	1.040	0.970	1.040	0.944	0.688	0.922
0.884	1.140	1.100	1.320	0.980	1.070	0.684	0.684	1.130
0.704	1.200	1.140	1.160	0.880	1.130	0.670	0.688	0.904

GRAND MEAN 0.97289

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.14682	2	0.07341
N	0.32718	2	0.16359
SN	0.43766	4	0.10941
R	0.01780	2	0.00890
SR	0.01636	4	0.00409
NR	0.02011	4	0.00503
SNR	0.12506	8	0.01563
TOTAL	1.09098	26	

ANALYSIS OF VARIANCE.....MSELY2

LEVELS OF FACTORS

S	3
N	3
R	3

1.060	0.840	1.010	0.924	0.924	1.070	0.920	0.696	0.676
0.892	0.980	1.240	0.984	0.938	1.050	0.676	0.682	0.686
0.731	0.800	0.980	0.968	0.955	1.020	0.686	0.696	0.688

GRAND MEAN 0.83044

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.04705	2	0.02353
N	0.38905	2	0.19453
SN	0.05855	4	0.01464
R	0.02667	2	0.01334
SR	0.03989	4	0.00997
NR	0.04856	4	0.01214
SNR	0.03937	8	0.00492
TOTAL	0.64914	26	

ANALYSIS OF VARIANCE.....DRMON1

LEVELS OF FACTORS

S	3
N	3
R	3

1.064	0.864	0.966	0.984	0.744	0.744	1.144	0.904	0.984
1.064	0.664	0.504	0.664	0.966	0.680	1.024	0.944	1.376
1.024	0.764	0.834	0.984	0.926	0.830	1.154	1.064	1.124

GRAND MEAN 0.94030

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.08911	2	0.04456
N	0.28441	2	0.14221
SN	0.12426	4	0.03107
R	0.01040	2	0.00520
SR	0.05255	4	0.01314
NR	0.05839	4	0.01460
SNR	0.11930	8	0.01491
TOTAL	0.73844	26	

ANALYSIS OF VARIANCE.....DRMCN2

LEVELS OF FACTORS

S	3
N	3
R	3

0.984	1.064	0.744	0.824	0.704	0.864	0.904	0.984	0.944
0.916	0.966	0.944	0.924	0.704	0.660	1.224	0.864	0.660
0.924	0.998	0.944	0.904	0.724	0.726	1.264	0.944	0.784

GRAND MEAN 0.83195

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.14305	2	0.07153
N	0.16476	2	0.08238
SN	0.10146	4	0.02536
R	0.00644	2	0.00322
SR	0.04571	4	0.01143
NR	0.00633	4	0.00158
SNR	0.12965	8	0.01621
TOTAL	0.59741	26	

ANALYSIS OF VARIANCE.....CAPRI

LEVELS OF FACTORS

S	3
N	3
R	3

1.024	0.986	0.824	0.704	0.744	0.904	1.024	0.944	1.020
1.064	0.966	0.904	0.664	0.624	0.704	0.824	0.984	1.124
1.024	1.060	1.064	0.664	0.704	0.704	0.866	0.866	1.024

GRAND MEAN 0.88926

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01206	2	0.00603
N	0.42308	2	0.21154
SN	0.06012	4	0.01503
R	0.00560	2	0.00280
SR	0.00545	4	0.00136
NR	0.04520	4	0.01130
SNR	0.05139	8	0.00642
TOTAL	0.60290	26	

ANALYSIS OF VARIANCE.....CARB2

LEVELS OF FACTORS

S	3
N	3
R	3

```
0.944 1.104 0.824 0.744 0.904 0.704 1.064 0.704 0.904
1.104 1.184 0.744 0.704 0.904 0.704 0.744 0.744 0.744
0.904 1.024 0.744 0.664 0.624 0.664 0.704 0.704 0.704
```

GRAND MEAN 0.82540

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.06838	2	0.03419
N	0.23194	2	0.11597
SN	0.15241	4	0.03810
R	0.06838	2	0.03419
SR	0.02477	4	0.00619
NR	0.03695	4	0.00924
SNR	0.06270	8	0.00784
TOTAL	0.64154	26	

ANALYSIS OF VARIANCE.....STAT1

LEVELS OF FACTORS

S	3
N	3
R	3

```
0.864 0.904 1.144 0.752 0.696 1.040 1.020 0.824 0.944
0.944 1.064 1.344 0.320 0.692 0.906 0.986 0.726 0.934
0.864 1.380 1.020 0.940 0.944 0.944 1.284 0.904 0.950
```

GRAND MEAN C.95778

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.07151	2	0.03576
N	0.17404	2	0.08702
SN	0.23399	4	0.05850
R	0.06456	2	0.03229
SR	0.11973	4	0.02993
NR	0.04462	4	0.01116
SNR	0.08706	8	0.01088
TOTAL	0.79552	26	

ANALYSIS OF VARIANCE.....STAN2

LEVELS OF FACTORS

S	3
N	3
R	3

1.030	1.204	1.220	0.824	0.824	0.920	1.146	1.060	1.000
1.040	1.024	0.984	0.734	0.784	1.060	1.040	0.904	0.824
1.020	1.120	1.280	0.782	0.810	0.956	1.120	0.894	0.936

GRAND MEAN 0.95518

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01841	2	0.00921
N	0.29375	2	0.14688
SN	0.12643	4	0.03162
R	0.04176	2	0.02088
SR	0.00992	4	0.00248
NP	0.02654	4	0.00663
SNR	0.04495	8	0.00562
TOTAL	0.56171	26	

ANALYSIS OF VARIANCE.....TYEP1

LEVELS OF FACTORS

S	3
N	3
R	3

1.104	1.184	0.904	0.864	1.064	0.784	1.304	1.024	1.404
1.384	0.984	0.784	1.144	1.064	0.824	1.024	1.024	1.344
1.064	1.024	0.984	1.064	1.104	1.024	0.904	1.184	1.204

GRAND MEAN 1.06548

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.02074	2	0.01037
N	0.12670	2	0.06335
SN	0.28930	4	0.07233
R	0.00039	2	0.00019
SR	0.06708	4	0.01677
NR	0.07739	4	0.01935
SNR	0.15674	8	0.01959
TOTAL	0.73834	26	

ANALYSIS OF VARIANCE.....IYER2

LEVELS OF FACTORS

S	3
N	3
R	3

0.984	0.944	1.064	0.824	0.944	0.784	1.144	1.064	1.104
0.864	0.844	1.064	1.064	0.864	0.904	1.384	1.264	1.344
0.934	0.944	0.864	1.144	0.824	0.784	1.244	1.144	1.024

GRAND MEAN 1.01723

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.03920	2	0.01960
N	0.43742	2	0.21871
SN	0.04391	4	0.01098
P	0.04222	2	0.02111
SR	0.07111	4	0.01778
NR	0.08196	4	0.02049
SNR	0.03858	8	0.00482
TOTAL	0.75440	26	

ANALYSIS OF VARIANCE.....LCORI1

LEVELS OF FACTORS

S	3
N	3
R	3

```
1.740 1.180 0.944 1.024 0.984 0.984 1.264 1.140 1.144
1.144 1.150 1.024 0.864 1.060 1.080 1.104 0.866 1.040
1.424 1.220 0.944 0.944 0.944 1.020 1.240 1.140 1.264
```

GRAND MEAN 1.10689

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.10644	2	0.05322
N	0.20512	2	0.10256
SN	0.26640	4	0.06660
R	0.06794	2	0.03397
SR	0.08685	4	0.02171
NR	0.05963	4	0.01491
SNR	0.08406	8	0.01051
TOTAL	0.87643	26	

ANALYSIS OF VARIANCE....LCOPI2

D

LEVELS OF FACTORS

S	3
N	3
R	3

1.134	1.064	0.944	0.884	0.904	0.784	1.064	0.904	0.904
1.106	1.024	0.904	0.904	0.864	0.940	0.986	1.064	0.984
1.064	1.086	1.020	0.980	0.724	0.904	0.984	0.864	1.224

GRAND MEAN 0.97267

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.02761	2	0.01380
N	0.13470	2	0.06735
SN	0.03926	4	0.00981
R	0.00262	2	0.00131
SR	0.05963	4	0.01491
NR	0.01309	4	0.00327
SNR	0.05936	8	0.00742
TOTAL	0.33627	26	

ANALYSIS OF VARIANCE.....SEARSI

LEVELS OF FACTORS

S	3
N	3
R	3

0.864	1.064	0.864	0.744	0.664	0.944	0.744	0.904	1.384
0.944	1.272	0.784	0.904	0.664	1.056	1.064	0.984	1.384
1.024	0.784	0.744	0.944	0.744	0.744	0.824	1.104	1.104

GRAND MEAN 0.93326

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.06208	2	0.03104
N	0.24406	2	0.12203
SN	0.37037	4	0.09272
R	0.06276	2	0.03138
SR	0.09227	4	0.02307
NR	0.01259	4	0.00315
SNR	0.15567	8	0.01946
TOTAL	1.00031	26	

ANALYSIS OF VARIANCE.....SEARS2

LEVELS OF FACTORS.

S	3
N	3
R	3

1.064	1.104	0.744	1.064	0.864	0.664	0.864	1.224	1.204
0.864	0.864	1.144	0.904	0.744	0.904	1.024	1.144	1.064
0.904	0.924	1.184	0.944	0.744	0.704	0.944	0.866	1.244

GRAND MEAN 0.95592

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01282	2	0.00641
N	0.23308	2	0.11654
SN	0.16146	4	0.04036
R	0.01112	2	0.00556
SR	0.15222	4	0.03806
NR	0.00692	4	0.00173
SNR	0.17422	8	0.02178
TOTAL	0.75184	26	

ANALYSIS OF VARIANCE.....JOHNV1

LEVELS OF FACTORS

S	3
N	3
R	3

1.024	1.184	1.104	1.104	1.024	0.864	1.184	1.144	1.304
1.224	1.184	1.264	1.164	0.364	0.864	1.024	1.224	1.304
1.024	1.184	1.264	1.064	1.184	0.984	1.144	1.264	1.384

GRAND MEAN 1.13141

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.00892	2	0.00446
N	0.20465	2	0.10233
SN	0.14815	4	0.03704
R	0.01816	2	0.00908
SR	0.03277	4	0.00819
NR	0.03384	4	0.00846
SNR	0.05043	8	0.00630
TOTAL	0.49692	26	

ANALYSIS OF VARIANCE.....JOHNV2

LEVELS OF FACTORS

S	3
N	3
R	3

1.184	1.104	0.984	0.864	0.836	0.944	1.104	1.020	1.064
1.064	1.184	1.024	0.966	0.886	0.824	1.024	1.184	1.184
1.144	1.144	1.024	0.864	0.826	0.944	1.104	1.140	1.224

GRAND MEAN 1.03178

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.00082	2	0.00041
N	0.29775	2	0.14888
SN	0.04654	4	0.01164
R	0.00582	2	0.00291
SR	0.01767	4	0.00442
NR	0.00883	4	0.00221
SNR	0.03056	8	0.00382
TOTAL	0.40799	26	

ANALYSIS OF VARIANCE.....ELIAS1

LEVELS OF FACTORS

S	3
N	3
R	3

1.024	0.694	0.676	0.904	0.820	0.824	1.144	0.784	0.874
0.784	1.144	1.024	0.824	0.666	0.664	0.904	0.944	1.024
1.024	1.184	1.264	1.064	1.184	0.984	1.144	1.264	1.384

GRAND MEAN 0.96881

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.00156	2	0.00078
N	0.12333	2	0.06166
SN	0.03264	4	0.00816
R	0.53089	2	0.26545
SR	0.17575	4	0.04394
NR	0.08070	4	0.02018
SNR	0.12178	8	0.01522
TOTAL	1.06666	26	

ANALYSIS OF VARIANCE.....ELIAS2

LEVELS OF FACTORS

S	3
N	3
R	3

1.080	1.204	1.220	0.824	0.824	0.920	1.146	1.060	1.010
0.523	1.074	0.756	1.074	0.816	0.956	0.984	0.866	1.040
0.944	1.064	1.344	0.820	0.698	0.906	0.986	0.726	0.934

GRAND MEAN 0.96255

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.03519	2	0.01760
N	0.15616	2	0.07808
SN	0.08488	4	0.02122
R	0.06402	2	0.03201
SR	0.05121	4	0.01280
NR	0.16709	4	0.04177
SNR	0.07852	8	0.00981
TOTAL	0.63703	26	

ANALYSIS OF VARIANCE.....DAAKS1

LEVELS OF FACTORS

S	3
N	3
R	3

0.744	0.626	1.484	0.984	0.864	0.916	0.986	0.666	0.904
0.944	0.944	0.904	0.944	0.744	0.896	0.996	0.744	0.916
1.064	0.664	1.026	0.966	0.676	0.816	0.864	0.704	0.784

GRAND MEAN 0.88037

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.27924	2	0.13962
N	0.04112	2	0.02056
SN	0.10905	4	0.02726
R	0.02264	2	0.01132
SR	0.10116	4	0.02529
NR	0.01083	4	0.00271
SNR	0.21400	8	0.02675
TOTAL	0.77805	26	

ANALYSIS OF VARIANCE.....DAAWS2

LEVELS OF FACTORS

S	3
N	3
R	2

1.058	1.060	0.874	0.716	0.664	0.744	0.366	1.024	1.184
1.028	1.064	0.904	0.696	0.364	0.744	0.936	1.064	1.084
1.060	1.124	0.944	0.716	0.744	0.646	1.024	1.024	1.266

GRAND MEAN 0.52859

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01577	2	0.00789
N	0.56325	2	0.28162
SN	0.13621	4	0.03405
R	0.00937	2	0.00468
SR	0.00868	4	0.00217
NR	0.01702	4	0.00425
SNR	0.03276	8	0.00410
TOTAL	0.78306	26	

ANALYSIS OF VARIANCE.....PETER1

LEVELS OF FACTORS

S	3
N	3
R	3

1.304	1.264	1.180	1.500	1.360	0.944	1.064	1.264	1.304
1.264	1.064	1.264	1.540	1.224	1.184	1.064	1.184	1.024
1.266	1.180	1.080	1.340	1.380	1.230	1.144	1.024	1.220

GRAND MEAN 1.21704

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.06197	2	0.03098
N	0.11172	2	0.05586
SN	0.15018	4	0.03755
R	0.00902	2	0.00451
SR	0.02671	4	0.00668
NR	0.02683	4	0.00671
SNR	0.13500	8	0.01688
TOTAL	0.52144	26	

ANALYSIS OF VARIANCE.....PETER2

LEVELS OF FACTORS

S	3
N	3
R	3

1.100	1.304	1.264	1.424	0.984	1.064	1.544	1.184	1.184
1.069	1.124	1.160	1.334	1.024	1.144	1.064	1.264	1.064
0.936	1.024	1.060	1.264	1.304	1.304	1.304	1.244	1.264

GRAND MEAN 1.18418

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01835	2	0.00918
N	0.08880	2	0.04440
SN	0.15959	4	0.03990
R	0.03186	2	0.01593
SR	0.06919	4	0.01730
NR	0.14430	4	0.03608
SNR	0.10166	8	0.01271
TOTAL	0.61374	26	

ANALYSIS OF VARIANCE.....YVETT1

LEVELS OF FACTORS

S	3
N	3
R	3

1.124	0.984	1.098	0.796	0.836	0.904	0.948	0.980	1.068
1.108	1.064	0.866	0.966	0.744	0.904	0.986	1.020	1.128
1.234	1.184	1.064	0.866	0.784	0.944	0.886	1.060	1.120

GRAND MEAN 0.98763

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01086	2	0.00543
N	0.23398	2	0.11699
SN	0.08836	4	0.02209
R	0.01082	2	0.00541
SR	0.01527	4	0.00382
NR	0.02695	4	0.00674
SNR	0.03837	8	0.00480
TOTAL	0.42462	26	

ANALYSIS OF VARIANCE..... YVETT2

LEVELS OF FACTORS

S	3
N	3
R	3

1.112	1.040	0.985	0.866	0.744	0.886	0.904	1.068	1.230
1.238	1.084	0.866	0.904	0.866	0.944	0.948	1.020	1.180
1.130	0.988	1.070	0.904	0.836	0.826	0.986	1.120	1.105

GRAND MEAN 0.99448

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.00623	2	0.00311
N	0.22613	2	0.11306
SN	0.13688	4	0.03422
R	0.00258	2	0.00129
SR	0.00999	4	0.00250
NR	0.00677	4	0.00169
SNR	0.04491	8	0.00561
TOTAL	0.43349	26	

ANALYSIS OF VARIANCE.....RUNDK1

LEVELS OF FACTORS

S	3
N	3
R	3

```
1.200 0.866 1.156 0.776 0.886 1.246 0.856 0.966 0.956
1.166 1.046 0.796 0.786 0.926 1.066 1.046 1.366 0.916
1.066 0.886 1.296 0.716 0.826 1.196 0.816 0.916 0.896
```

GRAND MEAN 0.98615

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.06923	2	0.03462
N	0.06388	2	0.03194
SN	0.32454	4	0.08114
R	0.01419	2	0.00710
SR	0.19259	4	0.04815
NR	0.09529	4	0.02382
SNR	0.04453	8	0.00557
TOTAL	0.80429	26	

ANALYSIS OF VARIANCE.....PONDK2

LEVELS OF FACTORS

S 3

N 3

P 3

0.896 0.966 0.826 0.766 0.726 1.133 1.196 0.806 0.936
0.926 1.216 1.066 0.776 0.776 1.056 1.076 0.786 0.736
0.896 1.236 1.056 0.736 0.366 1.220 1.026 0.956 1.216

GRAND MEAN 0.95715

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.06656	2	0.03328
N	0.06016	2	0.03008
SN	0.36823	4	0.09206
R	0.06081	2	0.03040
SR	0.08096	4	0.02024
NR	0.06651	4	0.01663
SNR	0.04245	8	0.00531
TOTAL	0.74569	26	

ANALYSIS OF VARIANCE.....LEN1

LEVELS OF FACTORS

S	3
N	3
R	3

```
1.264 0.606 0.904 0.744 0.664 0.744 1.184 1.184 1.467
1.104 0.706 0.864 0.704 0.744 0.744 1.384 1.424 1.184
1.064 0.664 0.944 0.906 0.784 0.784 1.584 1.464 1.536
```

GRAND MEAN 1.01293

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.16068	2	0.08034
N	1.90331	2	0.95166
SN	0.19935	4	0.04984
R	0.06329	2	0.03164
SR	0.04771	4	0.01193
NR	0.06353	4	0.01588
SNR	0.08298	8	0.01037
TOTAL	2.52085	26	

ANALYSIS OF VARIANCE.....LEN2

LEVELS OF FACTORS

S	3
N	3
R	3

0.904	0.784	0.904	0.984	0.864	0.664	0.864	1.224	1.104
1.144	1.144	0.664	0.784	0.944	0.704	0.904	1.224	0.904
0.984	0.944	0.664	0.904	0.664	0.664	0.904	0.904	1.464

GRAND MEAN 0.91881

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.05310	2	0.02655
N	0.30193	2	0.15099
SN	0.26193	4	0.06548
R	0.00581	2	0.00290
SR	0.15170	4	0.03793
NR	0.04681	4	0.01170
SNR	0.22234	8	0.02779
TOTAL	1.04367	26	

ANALYSIS OF VARIANCE.....JDSAM1

LEVELS OF FACTORS

S	3
N	3
R	3

```
1.240 0.944 0.744 0.784 0.864 1.064 1.024 1.224 1.224
1.084 0.964 0.864 0.766 0.904 1.104 0.944 1.064 1.128
0.986 0.984 0.904 0.784 0.944 0.984 1.064 1.108 1.108
```

GRAND MEAN 0.98089

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.01115	2	0.00558
N	0.17230	2	0.08615
SN	0.24539	4	0.06135
R	0.00864	2	0.00432
SR	0.01457	4	0.00364
NR	0.01340	4	0.00335
SNR	0.05724	8	0.00715
TOTAL	0.52271	26	

ANALYSIS OF VARIANCE.....JOSAM2

LEVELS OF FACTORS

S	3
N	3
R	3

0.904	0.784	0.824	0.984	1.064	1.024	0.904	1.224	1.544
0.984	0.984	0.864	0.784	0.984	1.144	1.184	1.264	1.504
0.984	0.744	1.064	0.864	0.984	0.904	0.944	1.064	1.504

GRAND MEAN 1.03733

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
S	0.19769	2	0.09884
N	0.56000	2	0.28000
SN	0.26204	4	0.06551
R	0.02382	2	0.01191
SR	0.01742	4	0.00436
NR	0.04658	4	0.01164
SNR	0.10524	8	0.01316
TOTAL	1.21280	26.	

APPENDIX H

GRAPHS - PERFORMANCE TIME Vs NOISE LEVELS

Graphs - Performance Time Vs Noise Levels

GUIDE TO GRAPHS

Y - Axis - Performance Time in seconds

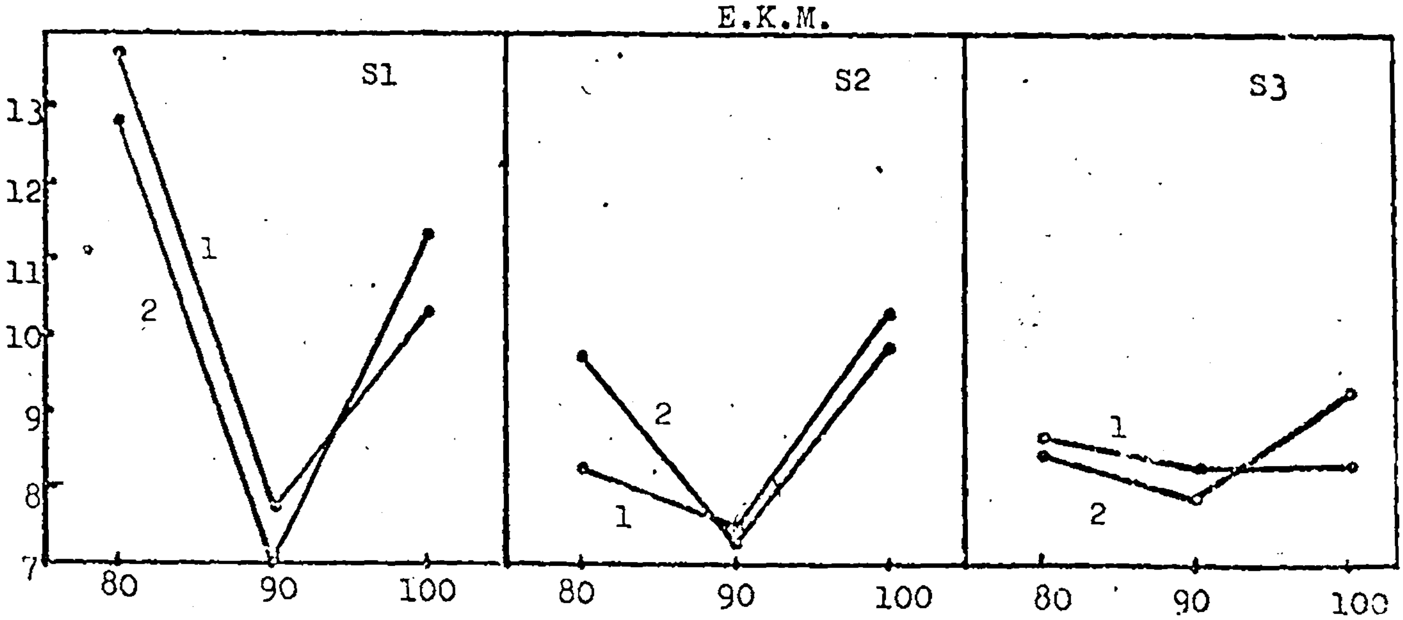
X - Axis - Noise Levels

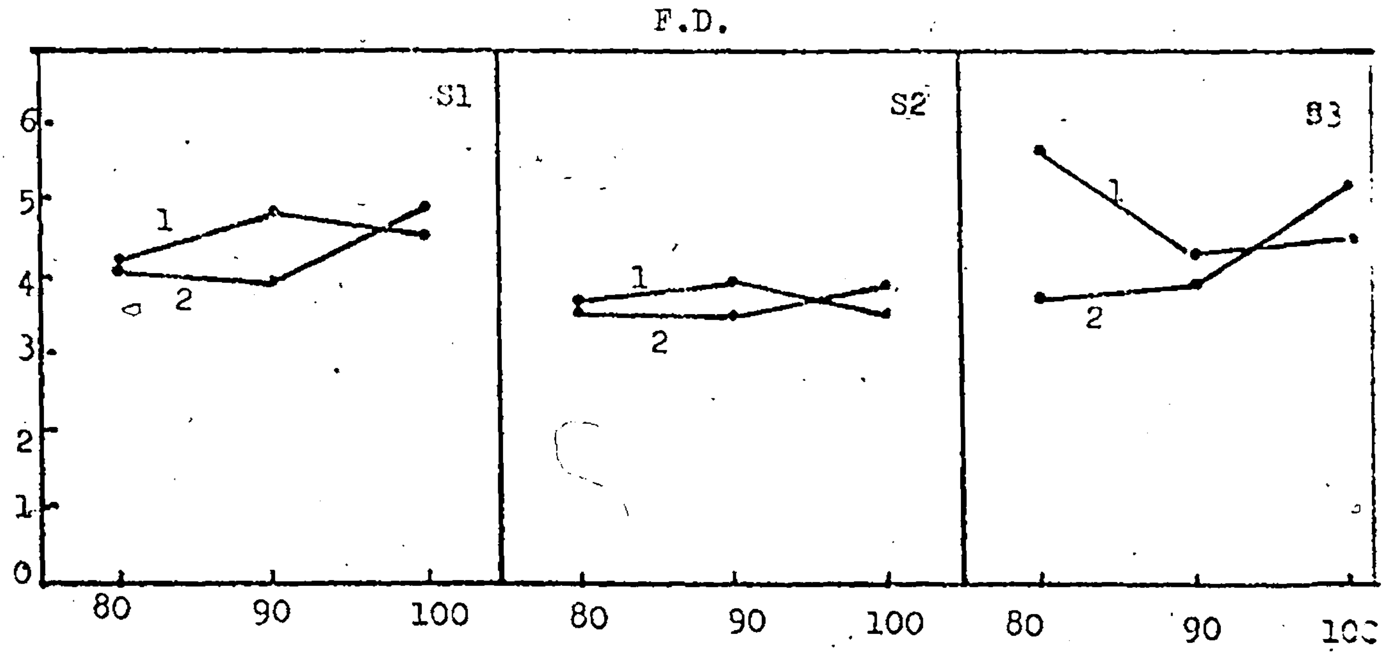
S1, S2, S3 - Speed Levels (S1 = 30, S2 = 40, S3 = 50)

'1' indicates side shift magnitude of 1.5 ft/sec.

'2' indicates side shift magnitude of 2.5 ft/sec.

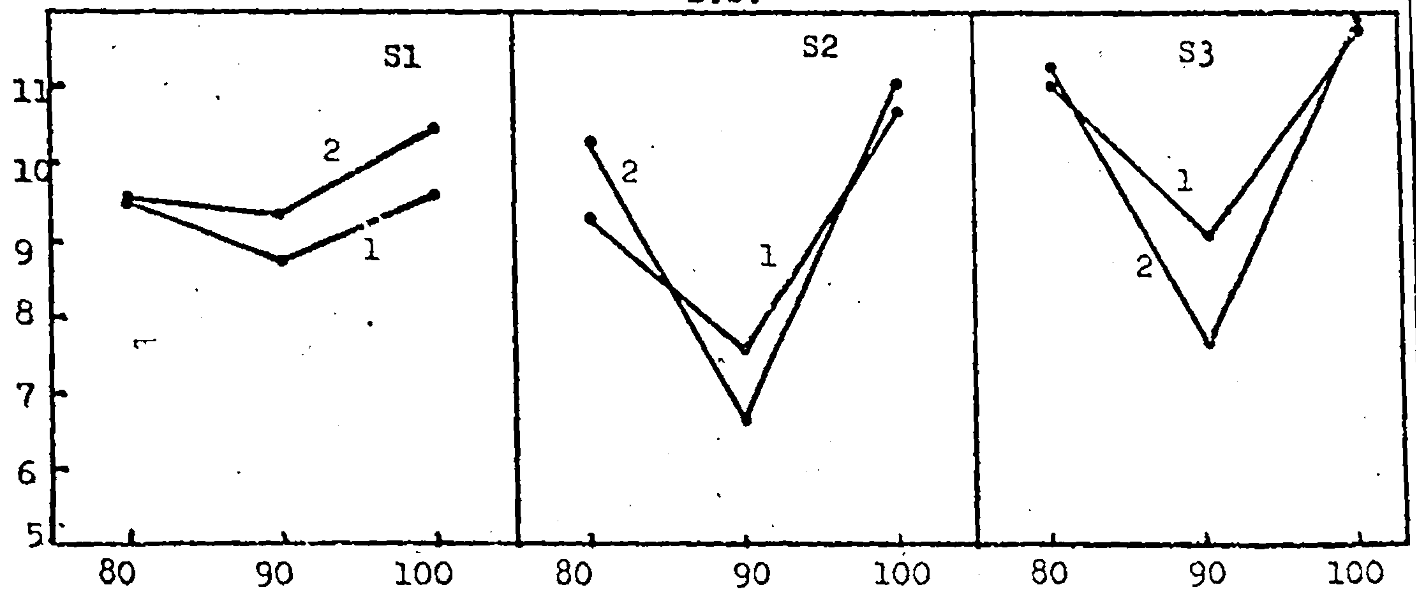
Y-axis...Performance Time..msx100





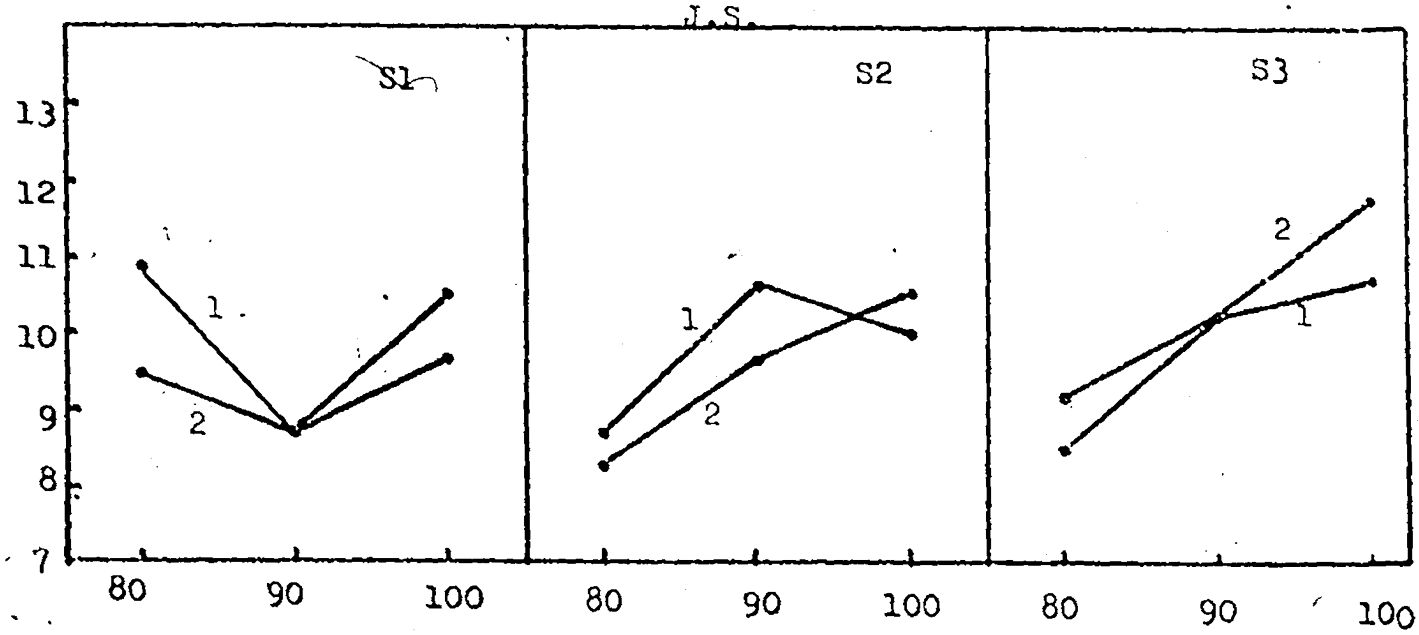
Y-axis...Performance Time..msx100

B.S.



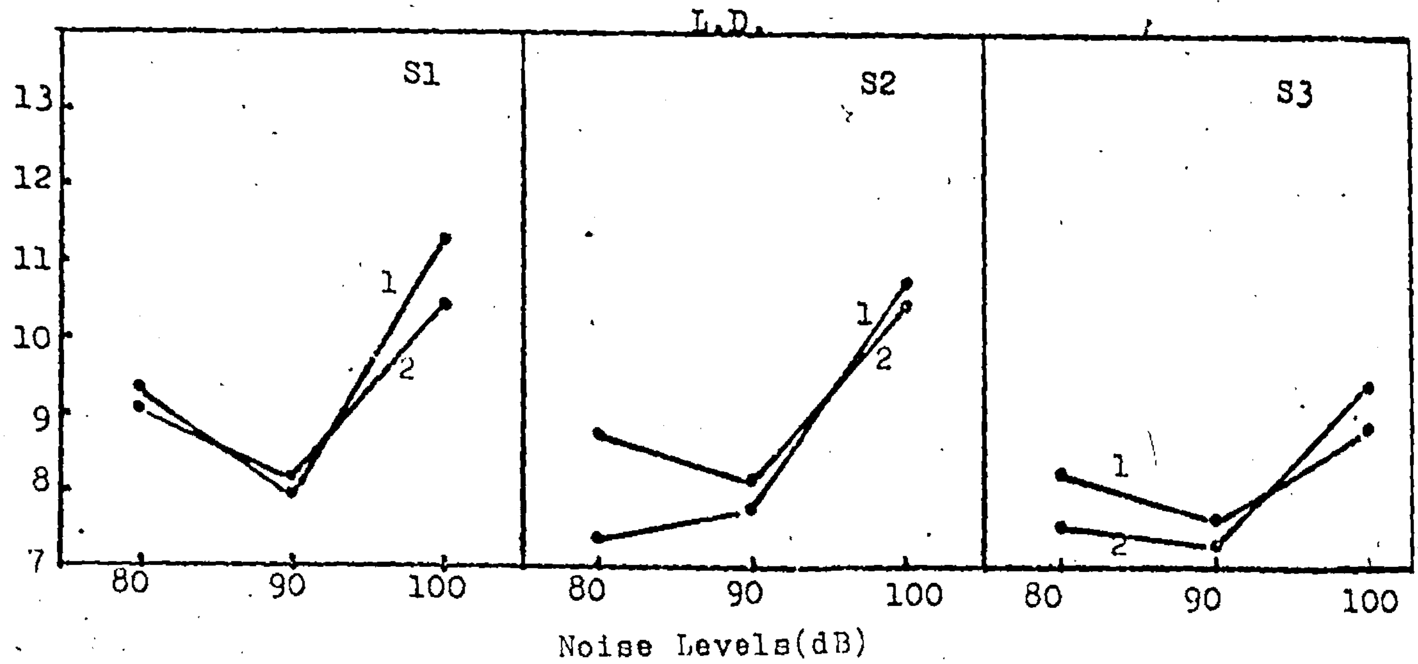
Noise Levels(dB)

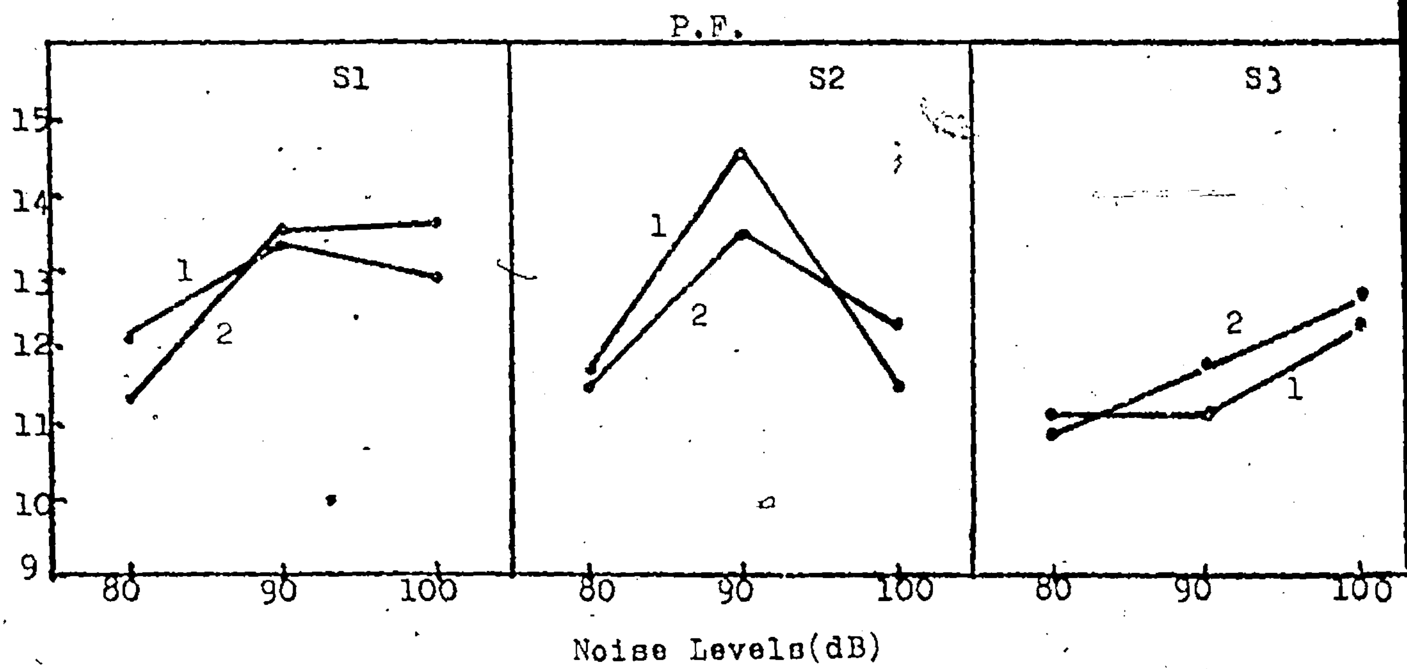
J.S.



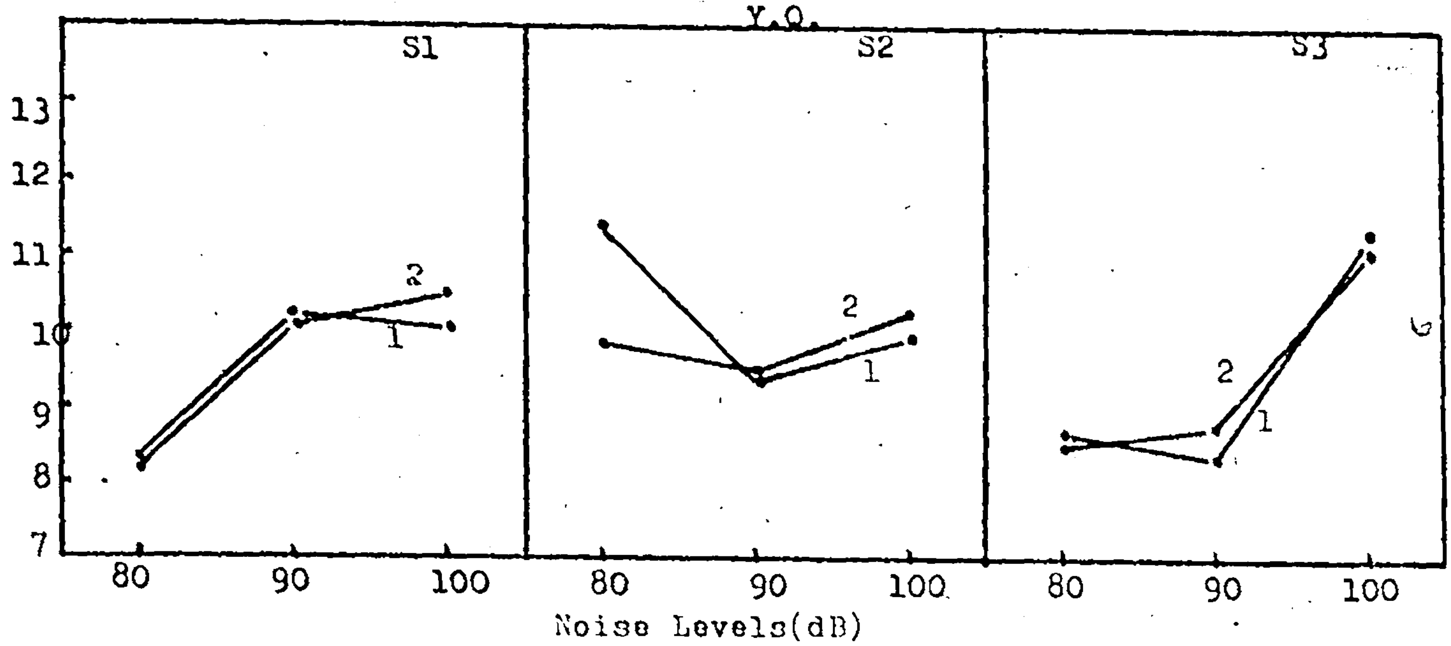
Noise Levels(dB)

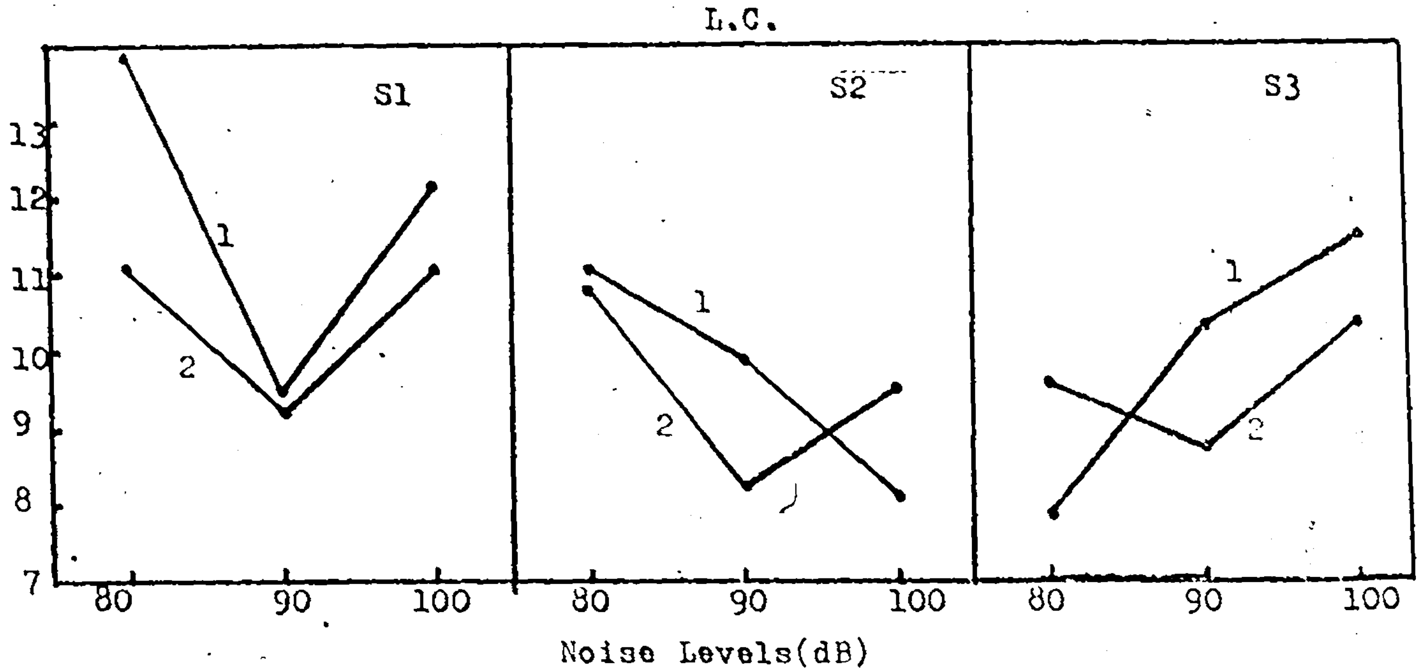
Y-axis...Performance Time..msx100



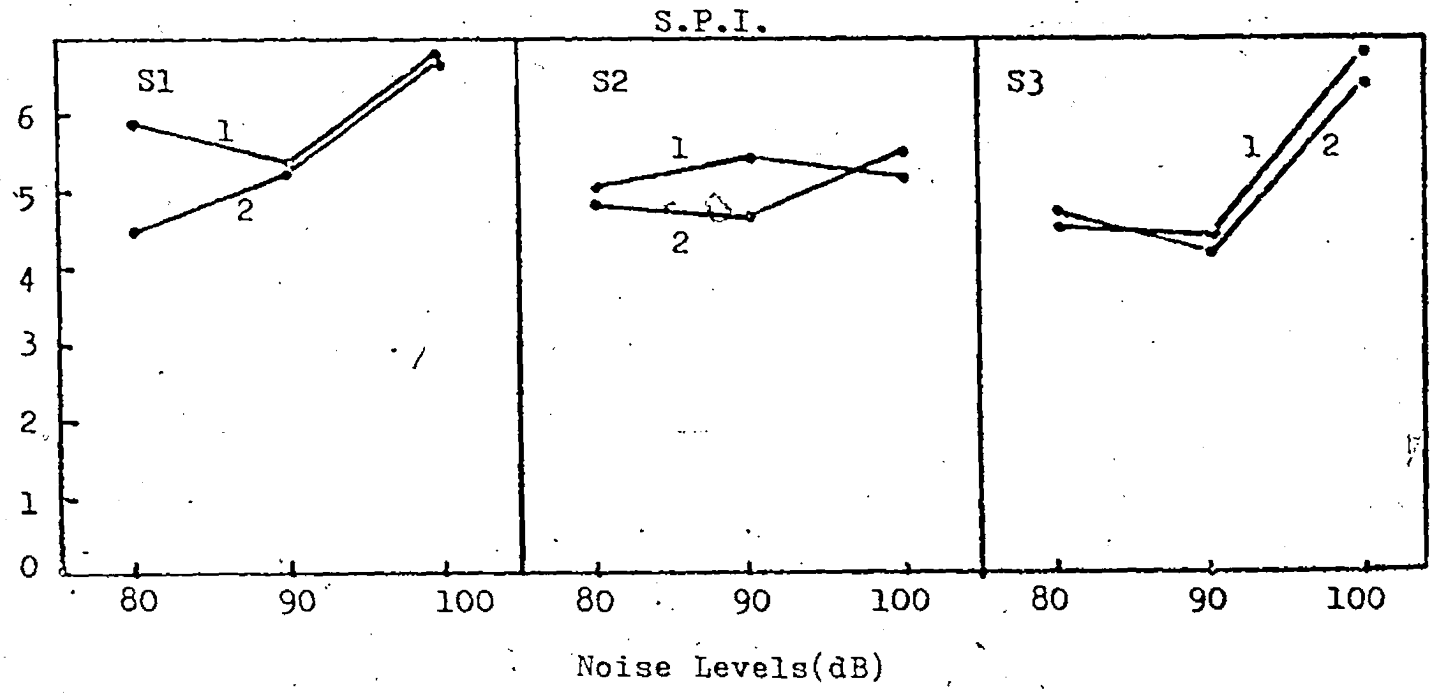


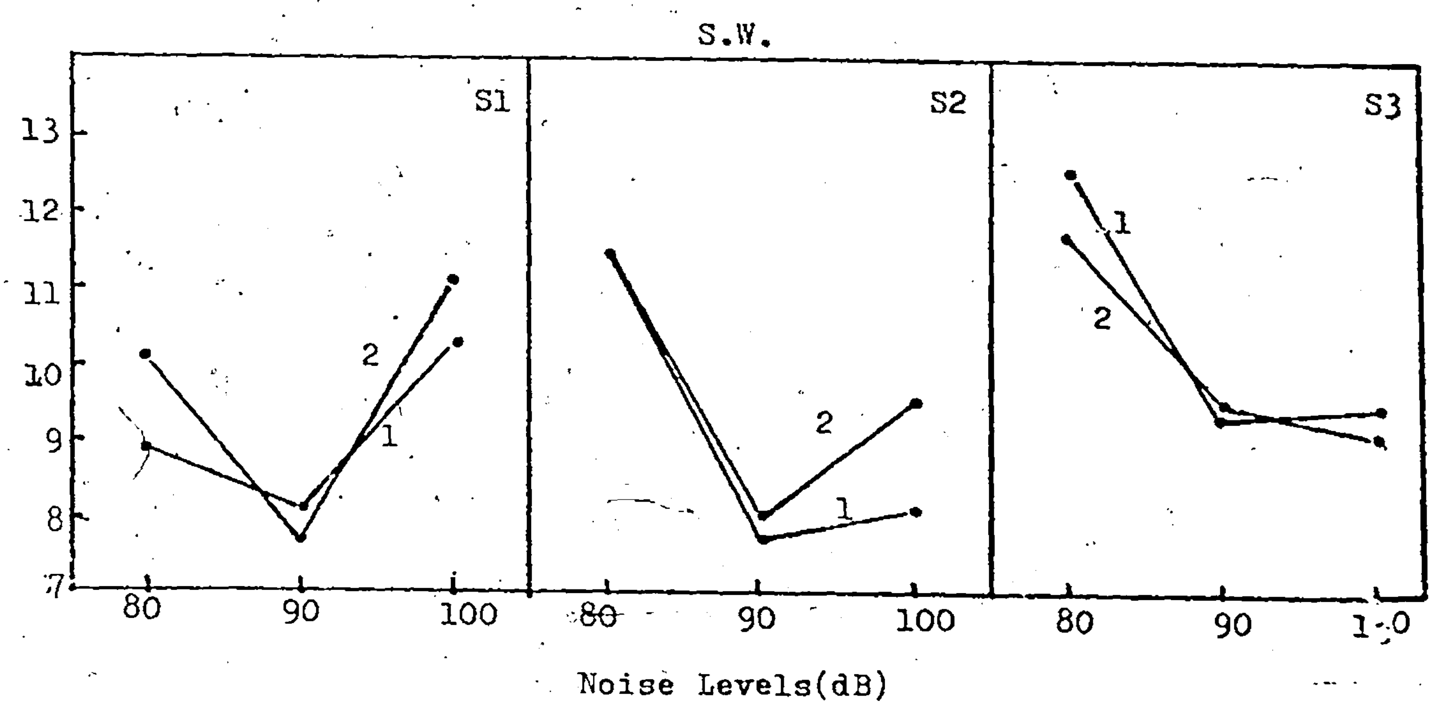
Y-axis...Performance Time..msx100



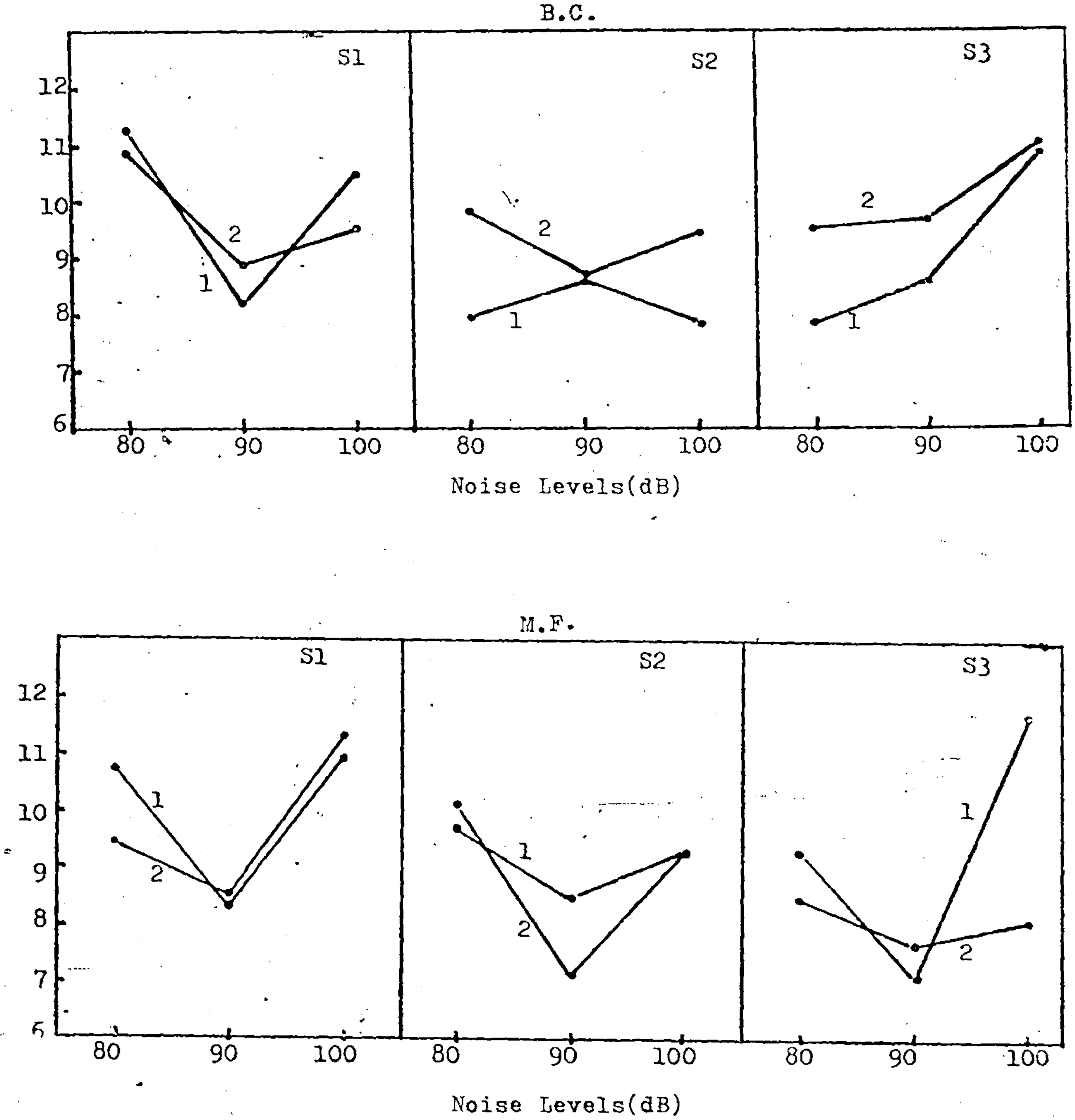


Y-axis...Performance Yime..msx100

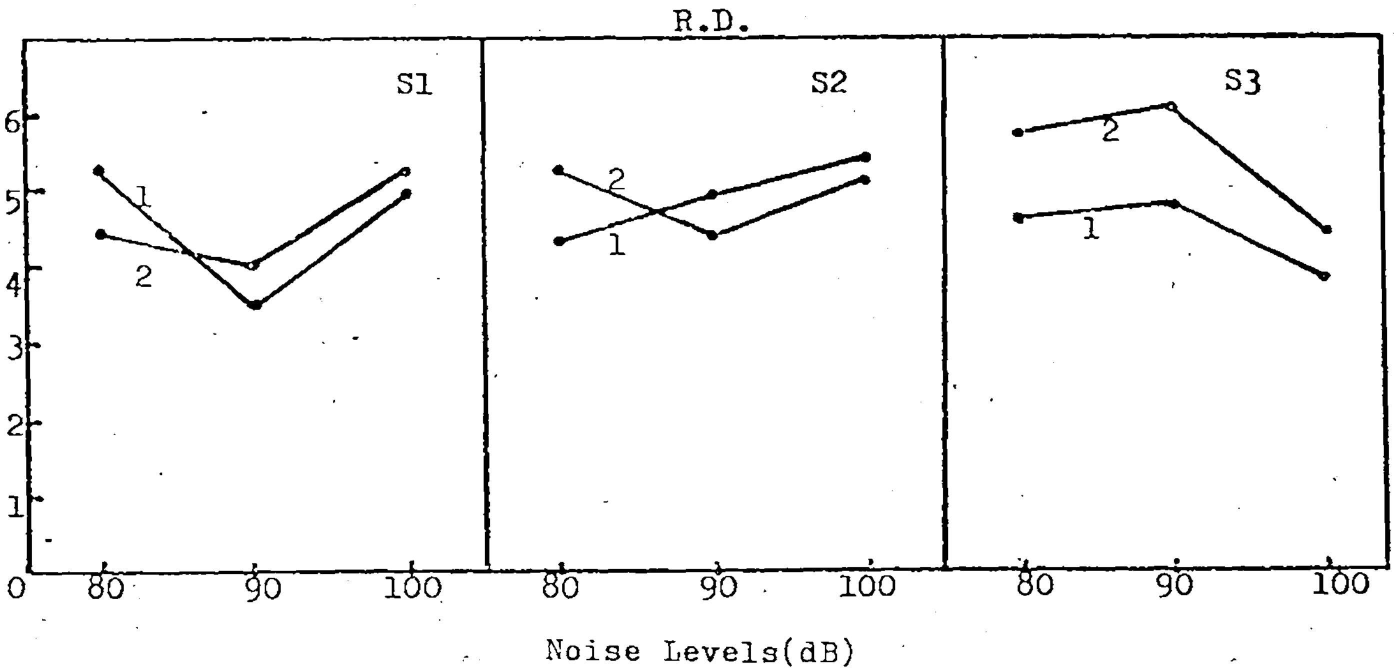


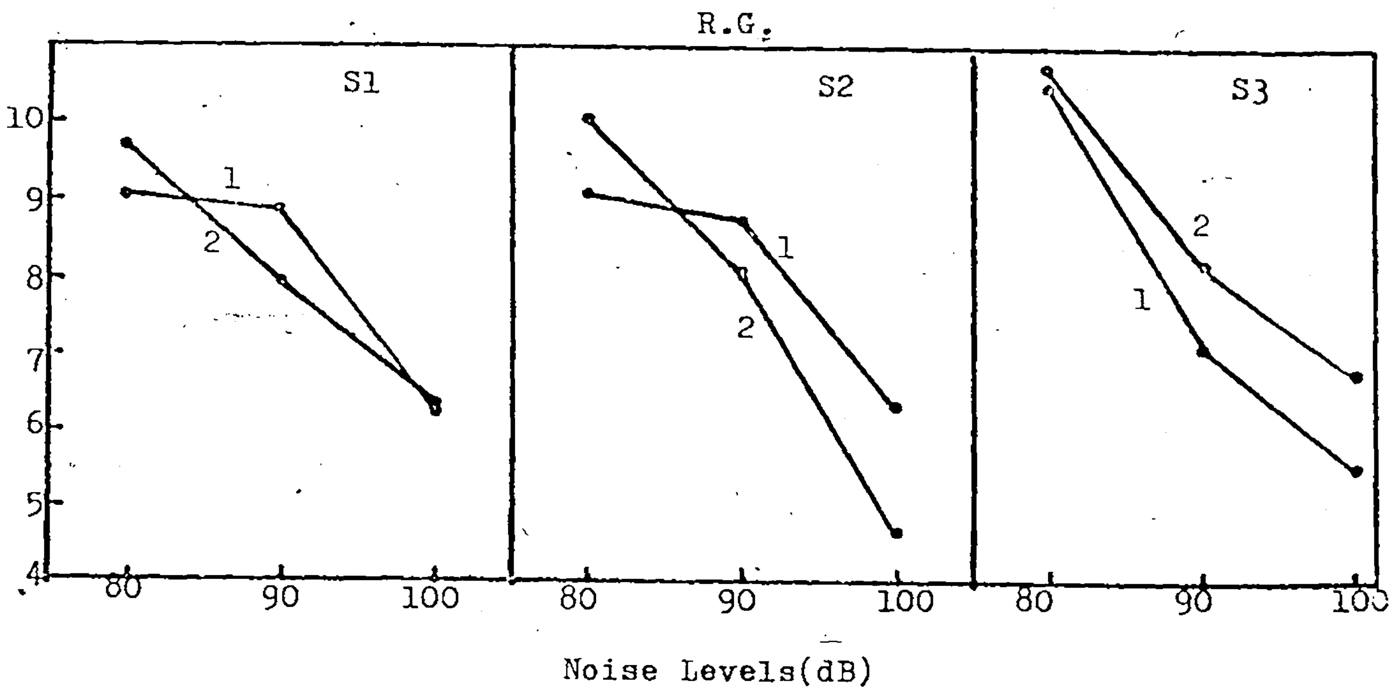


Y-axis...Performance Time..msx100



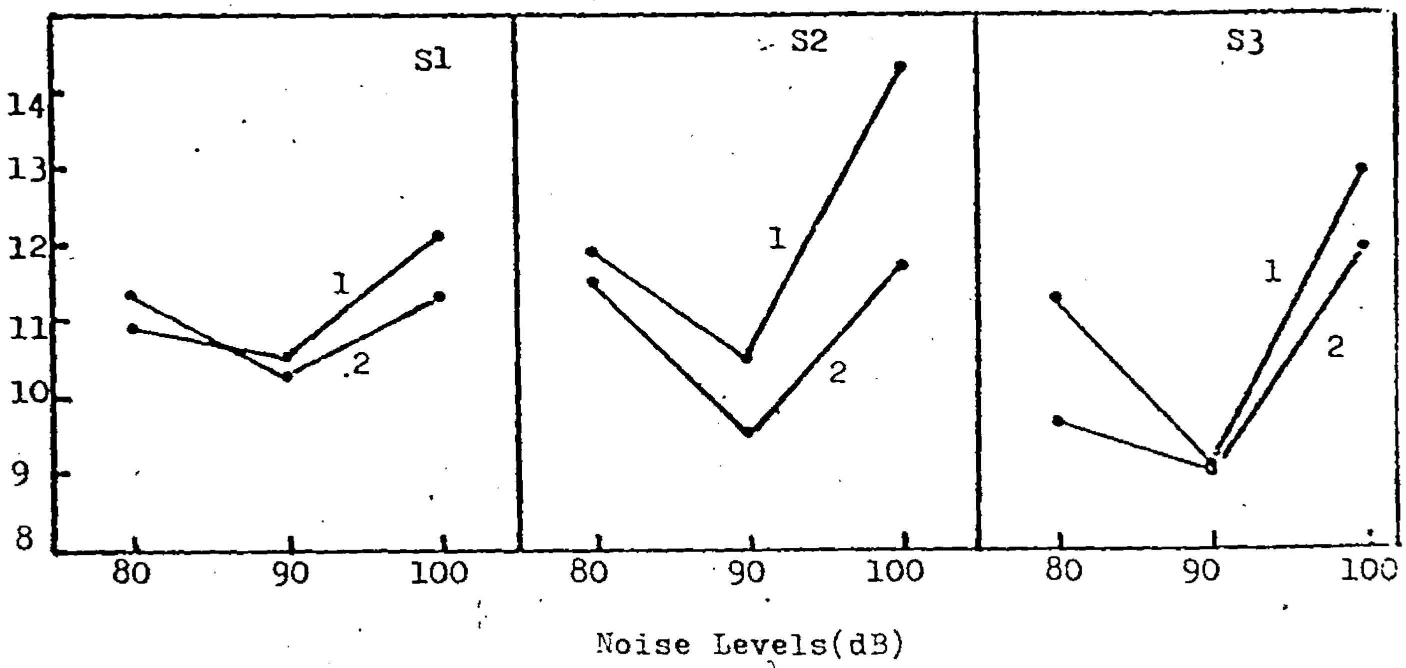
Y-axis...Performance Time..msx100



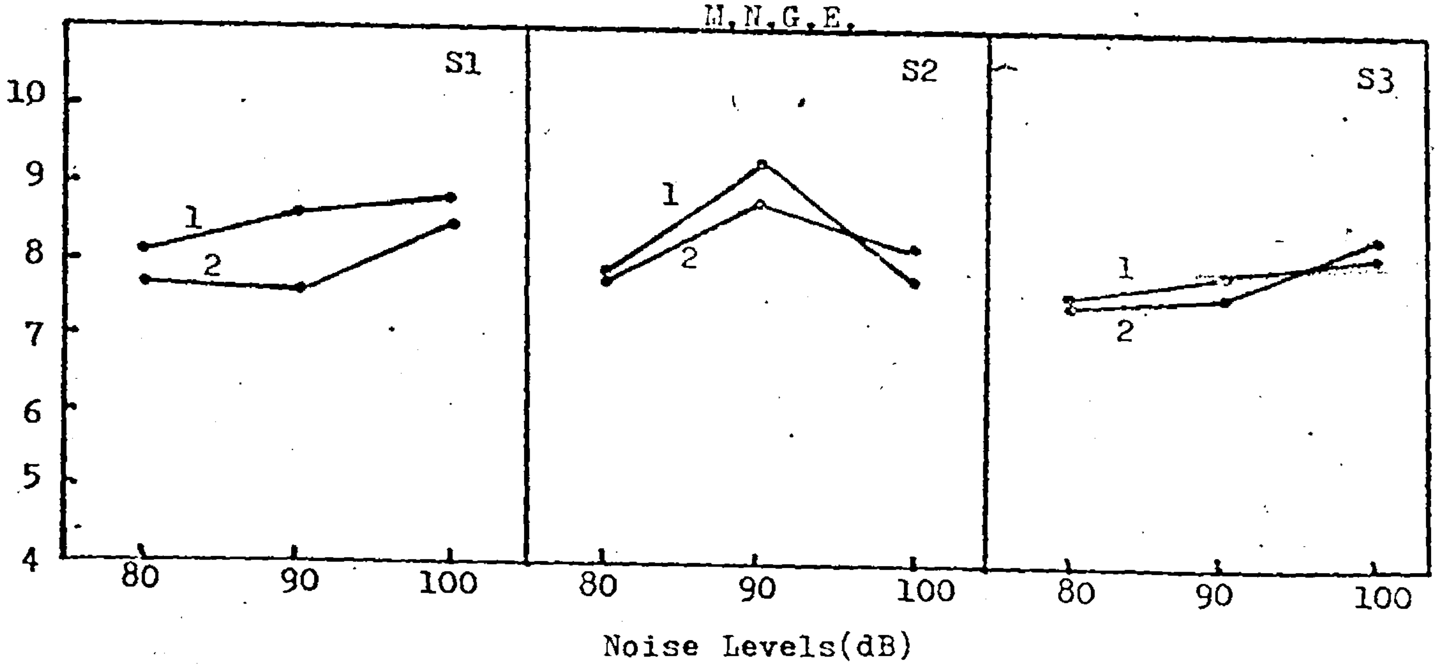


Y-axis....Performance Time..msx100

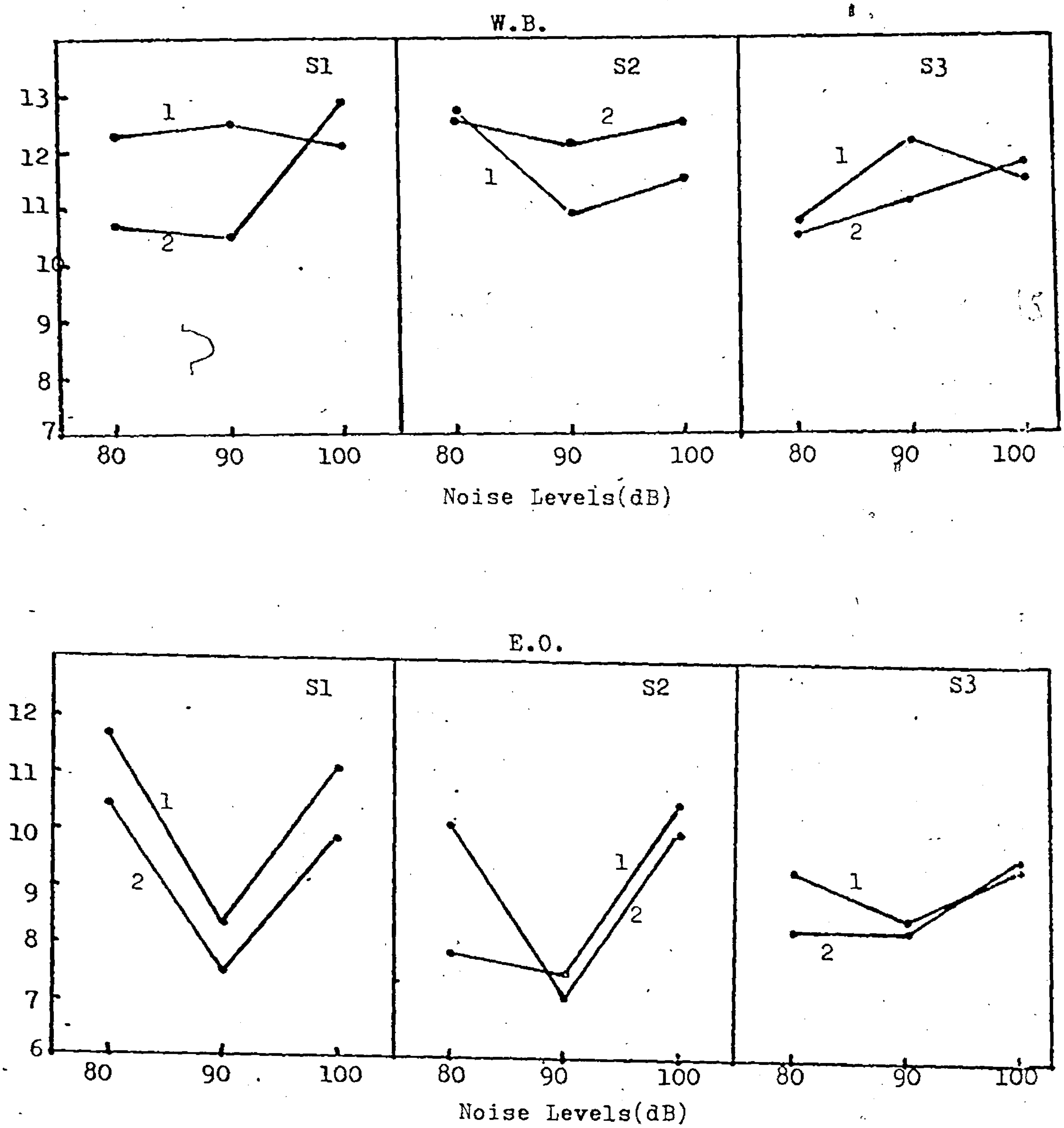
V.V.J.



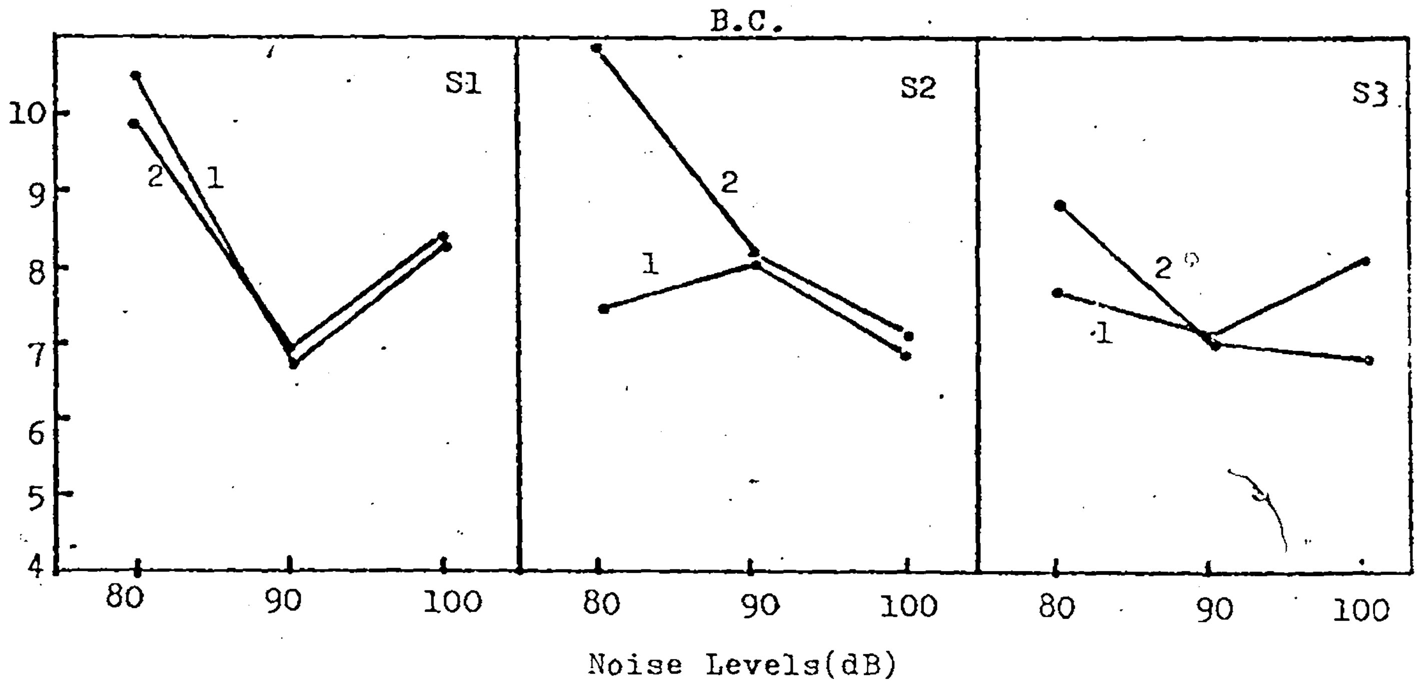
M.N.G.E.

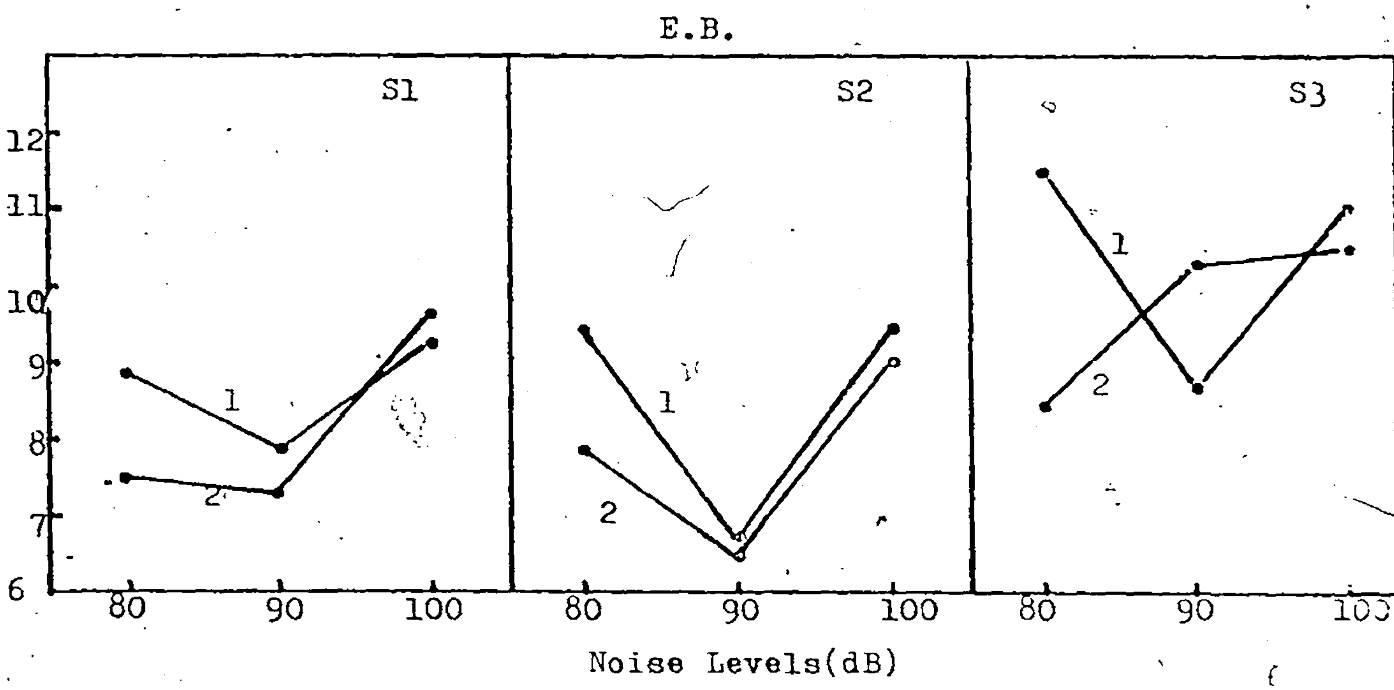


Y-axis...Performance Time..msx100

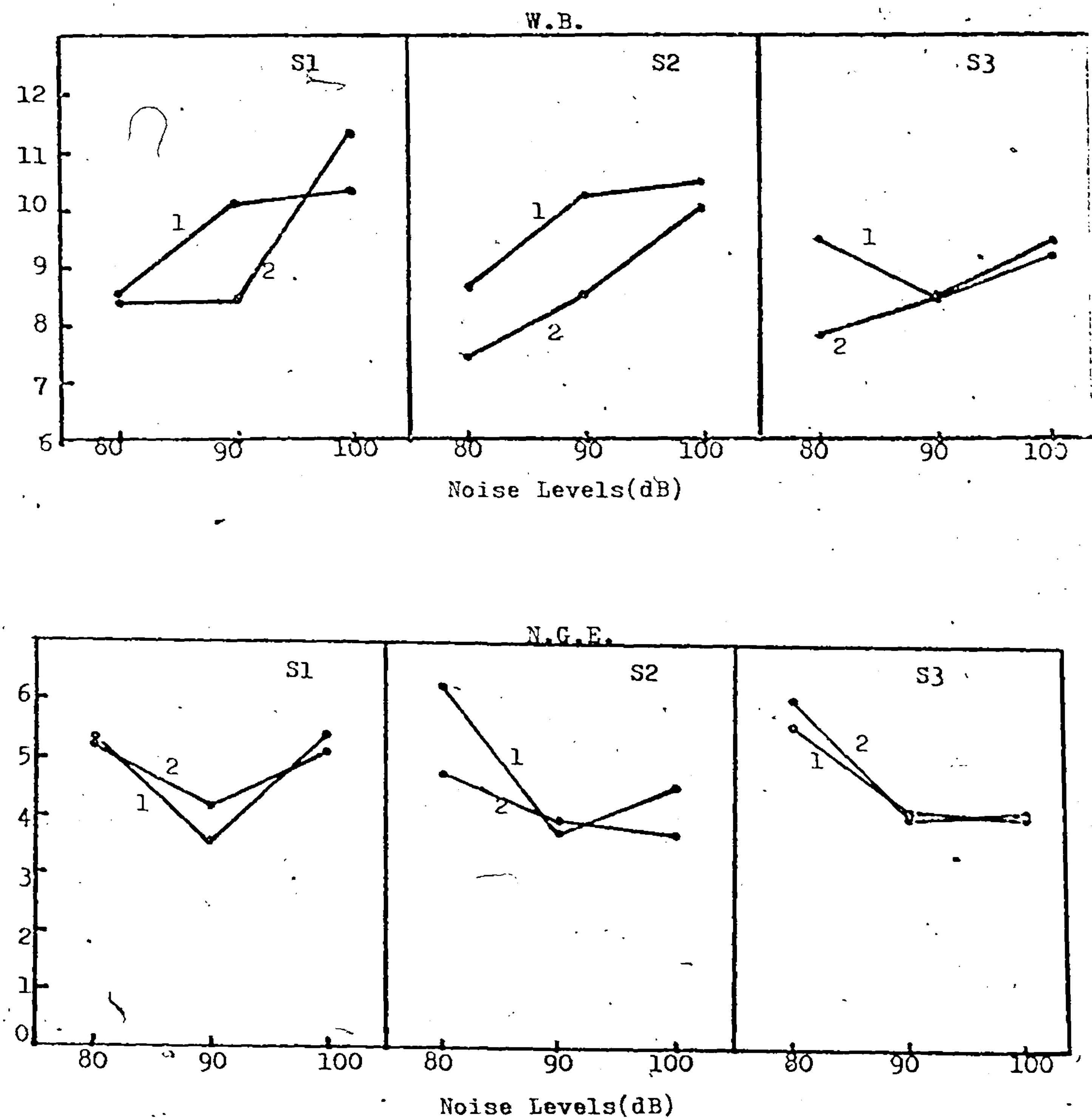


Y-axis...Performance Time..msx100





Y-axis...Performance Time..msx100



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1962	Graduated from St. Albert's College, Kerala, India with a Bachelor of Science Degree in Physics and Mathematics.
1962-1963	Worked as an instrument mechanic for a fertilizer company.
	Proceeded to United States with a scholarship and studied pre-engineering at St. Benedict's College in Atchison, Kansas.
1963	Entered St. Dunstan's University, Prince Edward Island, Canada.
1965	Received diploma in engineering and transferred to Nova Scotia Technical College, Halifax, Canada.
1967	Graduated from Nova Scotia Technical College with Bachelor of Engineering Degree in Electrical Engineering.
1967-1970	Worked as a design and project engineer for Northern Electric Co. Ltd., Toronto, Ontario, Canada.
1971	Accepted to the Graduate School of University of Windsor, Windsor, Ontario, Canada.
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